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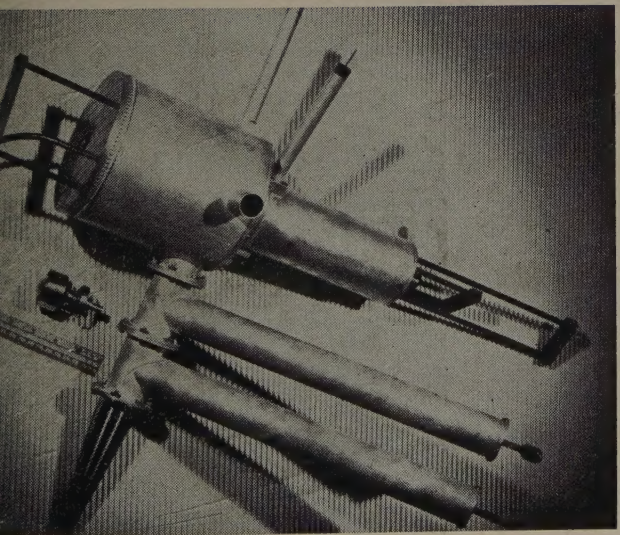

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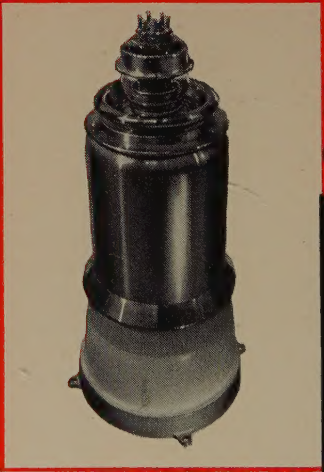

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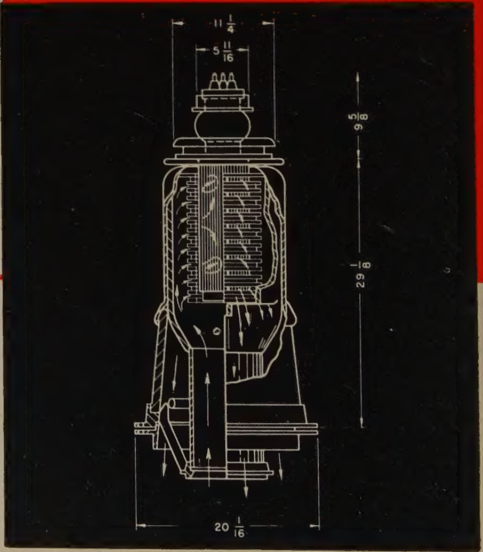

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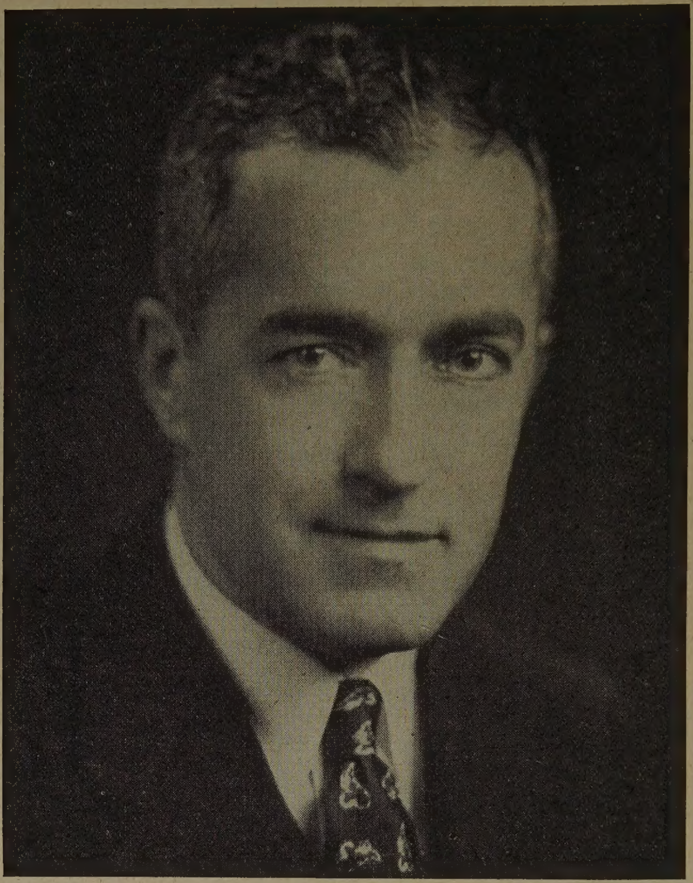

William H. Doherty

Director, 1951–1953

William H. Doherty was born in Cambridge, Mass., on August 21, 1907. He received the B.S. degree in electric communication engineering in 1927, and the M.S. degree in engineering in 1928, both from Harvard University. His studies completed, he spent a few months in the long-lines department of the American Telephone and Telegraph Company in Boston; thereupon he became a research associate in the radio section of the National Bureau of Standards, where he participated in a study of radio-wave phenomena. In June, 1929, he joined the radio-development department of Bell Telephone Laboratories at Whippany, N. J., where he took part in the development of high-power radio transmitters for transoceanic service and broadcasting. In the course of this work, he invented a high-efficiency linear power amplifier which is now extensively used in broadcasting, and for which he was awarded the Institute's Morris Liebmann Memorial Prize in 1937.

In 1938 Mr. Doherty began to devote himself to the pioneering work at Bell Laboratories in the fire-control radar field; during the war years he supervised a radar development group which was responsible for the design of a number of radars widely used on Navy surface ships and submarines for gunfire and torpedo control.

After the war, Mr. Doherty resumed supervision of AM and FM broadcast-equipment design, as well as continuing his association with Bell Laboratories military electronic developments. In January, 1949, he was transferred to his present position of director of electronic and television research at the Murray Hill Laboratory of his company.

Mr. Doherty became an Associate Member of the Institute in 1929, a Member in 1936, a Senior Member in 1943, and a Fellow in 1944. He was on the Membership Committee from 1943 to 1946, and has been a member of the Committee on Professional Groups since 1948.

Mr. Doherty is the author of numerous papers on radio-transmitting equipment and power amplifiers, which have appeared in the Proceedings as well as in other technical journals.

He is a member of Tau Beta Pi and Sigma Xi. In June, 1950, he received the honorary degree of Doctor of Science from the Catholic University of America.

The following guest editorial, from an engineering official of the Radio-Television Manufacturers Association, analytically and persuasively presents a viewpoint concerning "preferred numbers" at variance with that expressed in an earlier analysis of the subject on this guest-editorial page.

Each of these treatments is based on both a broad philosophy and a specific set of situations. The subject of "preferred numbers" is of major importance to engineers. For these reasons, these analyses are in the nature of "required reading" for design and production engineers.—*The Editor.*

Another Viewpoint on Preferred Numbers

VIRGIL M. GRAHAM

There seems to be some difference in opinion with regard to the matter of "preferred numbers," or series of preferred values for sizes, dimensions, weights, ratings, and so forth. One viewpoint was recently expressed in these pages,[1] and it is fitting that another one, differing from the first, should also be presented. Those who set up the system referred to in the previous article, feel that it is the only one which deserves to be termed "preferred numbers"; there are others, however, who take a broader view of the whole matter, and who do not regard any one series or system as sacrosanct. They view number series of a certain type as tools, with the appropriate tool being used for the work at hand, and they consider that the term "preferred numbers" applies to all series in which the increment from one number to another is a given percentage of the first.

It is unfortunate that there was no indication in the previous discourse as to the nature of the series chosen by the older ASA Standard, Z17.1–1936, R1946, as compared with the one used in the new ASA Standard on Preferred Values for Electronic Components, C16.15–1949, which also has wide international acceptance. It is known to many that the older system is based on a multiplier that is $\sqrt[10]{10}$ (probably because we are decimal-minded from having ten fingers), whereas the newer system is based on $\sqrt[12]{10}$, a multiplier giving a series which meets definite requirements. As was previously indicated, this latter figure was originally established for a specific product, namely, fixed composition resistors. Probably the most attractive feature of the twelfth-root series was that it fitted the generally accepted tolerance system of ±10 per cent, as well as the widely used color-coding system. (The companion sixth-root series and the twenty-fourth-root series accommodated the ±20 per cent and ±5 per cent tolerances.) The tenth-root series, as well as the fifth- and twentieth-root series, were seriously considered, but rejected as unsuitable. The twelfth-root series attained immediate acceptance by both the manufacturers and the users of these resistors. Subsequently its obvious usefulness for other electronic components led to its adoption on its own merits, and not because it was an "official RTMA list." That stage followed at a later date, when the system had already proved its usefulness in the component field. At that time it had become sufficiently clear that there was more to the system than just the meeting of an immediate single need. Apparently then, the introduction and use of the twelfth-root series indicated an appreciation of the usefulness of the preferred number concept far greater than that of the original. While there are those who deplore this "private" series because it differs from the work of one committee, there are others who would not shudder at the thought of additional series, if those presently used should prove inadequate. There would seem to be more danger from the first type of reasoning than from the latter. Imagine a national standardization committee "standardizing" a single system of machine screw threads for *all* purposes, including threads for pipes where we know that a great many very different requirements exist! Fantastic, yes, but uncomfortably close to the actual attitude of some toward the preferred number matter.

The concept of preferred numbers did not come into being a few years ago with the work of one committee which may or may not have been representative. On the contrary, it is generally known that this concept is a very old one. We are told that the Romans used such a series for water ducts, and that a Frenchman used one for balloon cables many years ago. Moreover, the American wire gauge is based on preferred numbers, and the tempered scale in music follows a twelfth-root series.

The understanding of the importance and value of the preferred number concept has been tremendously increased, along with the expanded use of preferred numbers, by the introduction of the twelfth-root series. The country and its industry undoubtedly derive a greater benefit from such an increase than they would from the attempted use of an unsuitable system which persists merely because it was standardized as an "ideal."

It would be interesting to know and to compare the total number of units of all sorts manufactured under both of the standard systems. This might indicate whether or not it was really only a "limited amount of benefit or temporary advantage" that was derived from the introduction of the twelfth-root series.

As long as standards are used as active tools, then standardization is of inestimable value to industry. However, if we allow standards to become fetishes, then standardization will be harmful and will wither.

---

[1] Arthur Van Dyck, "Preferred Numbers," Proc. I.R.E., vol. 39, p. 115; February, 1951.

Quality of Color Reproduction*

DAVID L. MacADAM†

Summary—**The evaluation of quality of color reproduction poses many complex problems. Optimum reproduction needs to be identified. Since it depends upon the limitations of the reproduction process, as well as upon human vision and judgment, optimum reproduction will probably have to be determined for each process separately. The program is to vary the production controls in systematic manners, measure the resulting color reproduction in the best way known (e.g., the I.C.I. method at the present time), submit the reproductions to visual judgment, and study the judgment data in comparison with the measurements in order to find significant correlations. The growing experience of such studies of color photography is suggested as a guide. Preliminary estimates of optimum reproduction and of seriousness of deviations may be based tentatively on results of studies of noticeability of color differences and on fragmentary results of studies of color photography. These estimates can be improved as various parts of the program are carried out.**

INTRODUCTION

"Complete theories do not fall from Heaven . . . " Freud.

WHEN ASKED how he obtained such delicate flesh tones in the nudes for which he is famous, Renoir is said to have replied, "I just keep painting and painting until I feel like pinching—then I know it's right." Color photography and color television are far from such perfection, but no better prescription for improvement can be written.

Judgment and measurement are indissoluble partners in the task of assessing quality of color rendering. Color can be measured, as can weight and height, but no formula can be trusted to distinguish pleasing from displeasing color, any more than a formula based on dimensions guarantees beauty of form. The principal value of measurements in such problems is that they permit something to be recorded about the occasion when satisfaction is experienced, or dissatisfaction expressed. The judgment, "I like that," is fundamental to all knowledge of what constitutes a good picture, but the knowledge is as evanescent as the picture if no measurements are made to record what the picture was, when it was approved. However, it is useless to make measurements blindly. The most revealing measurable characteristics of a picture, as of a beautiful form, can be discovered only by searching for whatever specifications are shared by all pleasing examples and more or less violated by less satisfactory ones.

Neither painters nor those in charge of color control in photography or television can hope to succeed by blind reliance on measurements. If a modern painter should venture to assert that he surpasses Renoir in the ability to render flesh tints, on the grounds that measurements prove his tints are closer to those of the living model, he would quite properly be dismissed with ridicule. Renoir's paintings do not, and probably never did, "match" the flesh of his models. This is not a criticism of Renoir, but an object lesson from which we should learn to investigate carefully before we rely upon "color-fidelity" measurements.

This paper is concerned with only the evaluation of color rendering. It is not concerned with the dependence of color on other technical or economic considerations. Such considerations might be the dependence of color reproduction on the available frequency bandwidth, on the relative widths of the color-separation channels, or on fineness of picture detail, or the necessity of eliminating flicker and edge or registration defects. These factors are discussed at length by other authors. This article is not based on any acquaintance with television, but on experience in the application of color measurements to color photography.

This paper can only outline the problem, and review the partial investigations that have been reported and are known to be in progress. Basically, the crucial questions are only asked, not answered. A program is suggested, modeled on one which seems to be productive in photography. No formula for the evaluation of the quality of reproduction is recommended. It is doubtful that any valid formula can be derived from the fragmentary and largely contradictory data now available concerning visual sensitivities and tolerances for color errors.

THE PSYCHOPHYSICAL APPROACH

There is nothing new in the suggestion that the quality of color in photography and television should be determined by visual observation and judgment. Nor is the idea of measuring the colors without precedent. The particular point of this discussion is that neither of these alone is adequate, but that a systematic combination offers the most promise.

The weakness of unaided judgment is shortness of memory. This is aggravated by the common tendency to jump to conclusions in order to aid memory. Without measurement there is no way of identifying, much less of remembering, relevant factors in the pictures judged or compared. Without written records, it is impossible to accumulate much experience.

The particular features of the design of picture-producing devices, and adjustments of the controls can, of course, be recorded. Although variations of these factors are convenient for sampling the enormous gamut of possible reproductions, these factors are not likely to be the most relevant measurable quantities for distinguishing good from poor rendering. The principles of color measurement, which will be briefly reviewed, are more likely than equipment design or controls to yield quantities which can be associated with the quality of color reproduction.

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* Decimal classification: R583×770.2836. Original manuscript received by the Institute, February 14, 1951.

† Eastman Kodak Company, Research Laboratory, Rochester, N. Y.

However, in themselves, color specifications lack any critical value. "Color fidelity," defined[1] as "the degree to which the television receiver reproduces the colors of the original scene," reveals a serious misconception of the purpose of both color television and color photography. This definition prejudges the facts, quite mistakenly, according to present indications. Optimum reproduction can be identified only by asking a number of people to indicate their preference and relative ratings of a widely representative variety of color renderings, by measuring many colors in the pictures, and by studying the color specifications in comparison with the relative grades assigned to the pictures by the judges. The discrepancies between the colors of the preferred picture (the norm) and those of the original scene may or may not be feasible to produce, but if such discrepancies are found, then "errors" of reproduction should be measured relative to the norm, rather than relative to the colors of the original scene.

Only after that norm is established can the question of the relative importance of various kinds of errors have any meaning. Such questions are important, and their answers are doubtless complex. They probably depend more seriously upon what the subject is, than upon its precise color in the original scene. Renoir's particular subject is not likely to be portrayed frequently in television or motion pictures, but human skin will probably be fairly high on the list of the most critical subjects.

MEASUREMENT OF COLOR

In order to measure a quality, such as color, we must conceive it as depending on the values of one or more variable quantities, and our first step is to determine the number of variables which are necessary and sufficient to determine the quantity of a color. No elaborate experiments are needed to decide that color can vary in three, and only three, independent ways. We can realize this by noting that color sensations can differ only in hue, saturation, and brightness. If we adjust one color so as to produce the same hue, saturation, and brightness as another, the two colors are indistinguishable.

For a very great variety of colors, such adjustment can be accomplished by varying the intensities of red, green, and blue light combined in the same area, by simultaneous superposition or by juxtaposition in such fine patterns that the separate components cannot be distinguished, or by successive presentation at a sufficiently high rate that the alternations of colors cannot be noticed. All hues and all brightnesses can be obtained in this manner. The only limitation is of saturation.

Very few, if any, pure colors from the spectrum can be matched with this scheme, and colors that are nearly as saturated as the spectrum are also unattainable. But practically all colors encountered in nature, art, and industry can be matched. The range of saturation producible depends upon the particular red, green, and blue chosen for the synthesis. The gamut depends somewhat on the hues of those components, but much more directly on their saturations. The greatest possible gamut would be obtained by using components as saturated as spectrally pure red, green, and blue. Colors of even greater saturation than the spectrum can be imagined, and can even be experienced, fleetingly, for example, by viewing spectrum green immediately after prolonged viewing of a bright, saturated red. More important, the amounts of different sets of red, green, and blue light necessary to match various colors are related by simple rules which can be extended to infer the amounts of physically impossible, supersaturated red, green, and blue primaries, the mixture of which would match every obtainable color, including even those of the spectrum.[2–4] These rules have been applied to extensive experimental data on the amounts of ordinary red, green, and blue components needed to match colors, and the results have been recommended by the International Commission on Illumination, and adopted by the American Standards Association as the basis for the measurement of color.

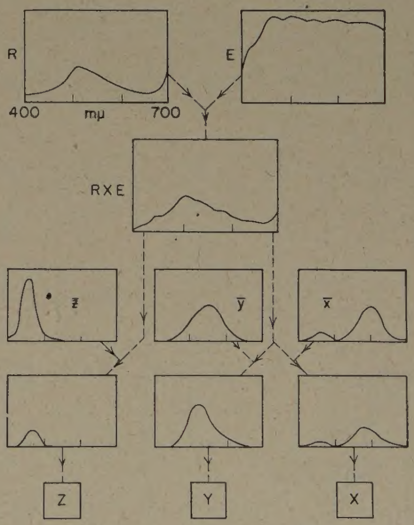

Fig. 1—Diagrammatic representation of principle of colorimetric specification.

The principles of color measurement are shown in Fig. 1, where E represents the spectral distribution of energy incident upon a reflecting sample, and R represents the spectral reflectance of the sample. The spectral distribution of the light reflected into the eyes of the observer is represented by the product curve, $R \times E$. If the spectral distribution of the light incident upon the eyes of the observer is measured directly, for instance, by spectro-

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[1] Senate Advisory Committee on Color Television, E. U. Condon, Chairman, "Present Status of Color Television," Senate Document 197, 81st Congress, Second Session, 1950; reprinted in PROC. I.R.E., vol. 38, pp. 980–1002, September, 1950.

[2] Staff of Color Measurements Laboratory, MIT, under direction of A. C. Hardy, "Handbook of Colorimetry," Massachusetts Institute of Technology Press, Cambridge, Mass.; 1936.

[3] W. D. Wright, "The Measurement of Colour," Adam Hilger Co. Ltd., London; 1944.

[4] P. J. Bouma, "Physical Aspects of Colour," N. V. Phillips Gloeilampenfabrieken, Eindhoven; 1944.

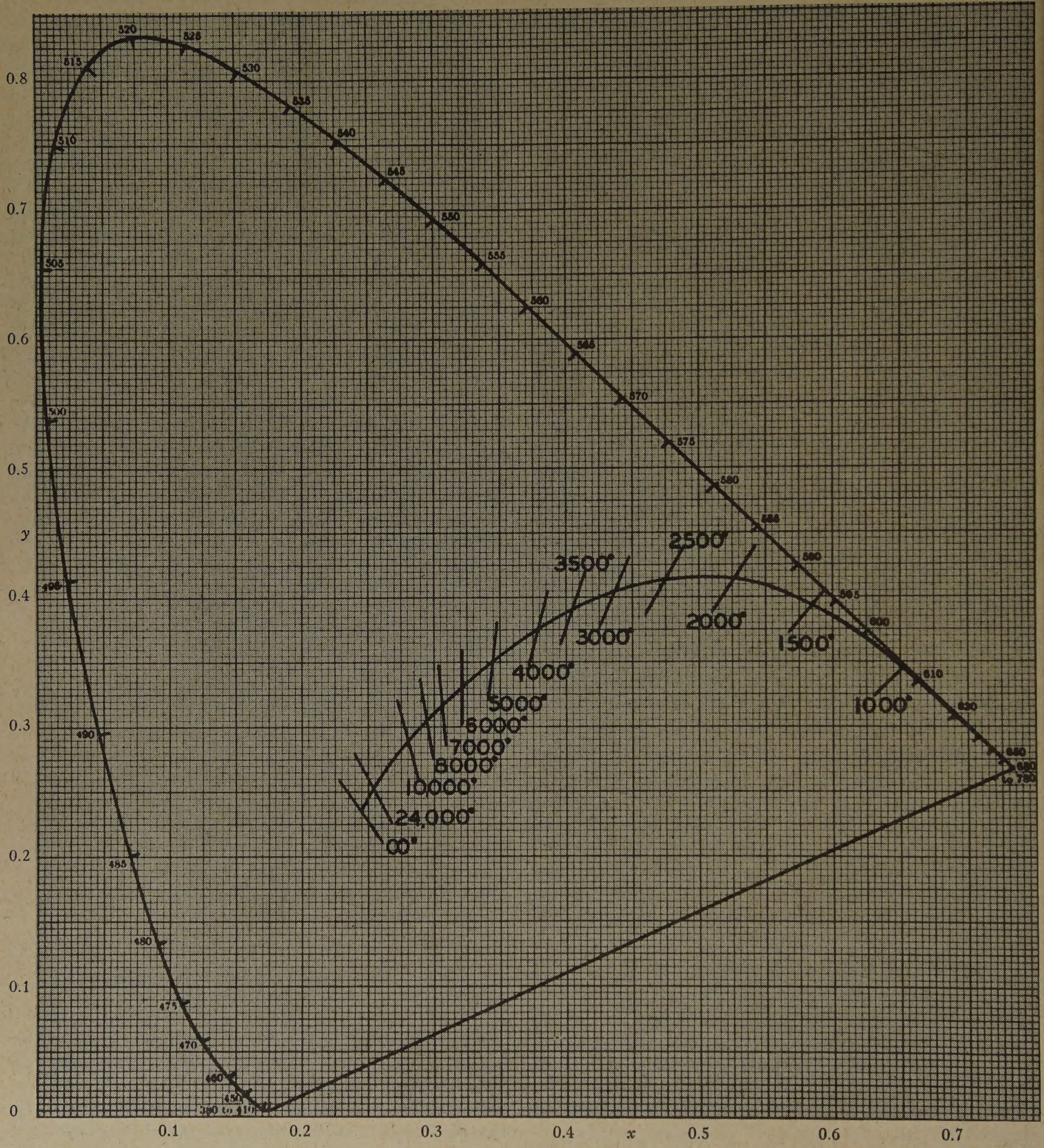

Fig. 2—Chromaticity diagram, showing locus of spectrum and locus of blackbody sources.

radiometry of the light from a television receiver, it can be used in place of the $R\times E$ curve. The standard I.C.I. spectral-weighting functions, which correspond to normal human color vision, are shown by the curves, $\bar{x}$, $\bar{y}$, and $\bar{z}$. The areas under the curves which result from weighting $R\times E$ by the $\bar{x}$, $\bar{y}$, and $\bar{z}$ functions are the quantities X, Y, Z of the supersaturated I.C.I. mixture components required to match the color of the sample. Routine methods of computation differ from this scheme only in details.[2,5,6]

In addition to including every color within their mixture gamut, the I.C.I. components have the convenient property that the quantity Y specifies luminance (the photometric evaluation of brightness). The remaining two variables of color specify chromaticity, which is most conveniently represented by a point on a plane diagram. Such a diagram might be constructed by simply plotting Z vertically and X horizontally. If the ratios Z/Y and X/Y were plotted, however, all colors having the same relative energy distribution would be represented by a single point, regardless of their intensity or luminance. This is a great convenience, since it enables us to study chromaticity independently of the intensity level. But the proportions of the resulting diagram are inconvenient. It is customary to plot, instead, the ratio $X/(X+Y+Z)$, horizontally, and the ratio, $Y/(X+Y+Z)$ vertically. The first ratio is abbreviated x and the second, y. The resulting diagram is shown in Fig. 2. The spade-shaped curve represents the colors of the spectrum, regardless of intensity. The straight line connecting its extremities represents the most saturated possible purples, from red at the right, through red purples near the center to blue purples and violet near the left corner. The curve tangent to the straight, long-wavelength (red) end of the spectrum locus and passing near the center of the diagram represents the colors of blackbody radiators[7] at various temperatures.

Since a blackbody at about 6,500° K has nearly the same color as daylight, and household tungsten lamps operate at about 2,800°K, any point near the corresponding segment of the blackbody locus may represent white, if the observer is adapted to the corresponding quality of illumination. This wide variation of the white criterion is an important fact. In one sense it is fortunate because, for example, it permits the same motion-picture films to be projected with tungsten lamps or with arc lamps of nearly daylight quality with very nearly equal satisfaction. Likewise, rather great variations of "balance" of color films and television pass unnoticed, provided that the picture controls the adaptation of the observer. However, if the surroundings are prominently illuminated, fluctuations of balance, and even the standard of white adopted for the production of the picture, can be very objectionable. This is presumably not important in theaters, because the illumination of the surround can be controlled. Greatest tolerance of the audience is obtained if the surrounding illumination is quite subdued, so that the picture, and its accidental variations of balance can control the adaptation.

The problem is much more difficult in the case of home television, because the ambient illumination may vary in quality from daylight to that from amber decorative luminaires, and the level of ambient illumination must be sufficient for easy movement and even for reading by uninterested members of the family. The choice of a standard for white that will be least objectionable under all likely conditions of adaptation is very difficult. This is not so critical in the case of "black-and-white" pictures, for which observers are quite tolerant of "off-white" tints. It is much more critical for color pictures, because attention is then directed to color, and departures from the observer's ever-changing criterion of white distort his perceptions of all colors.

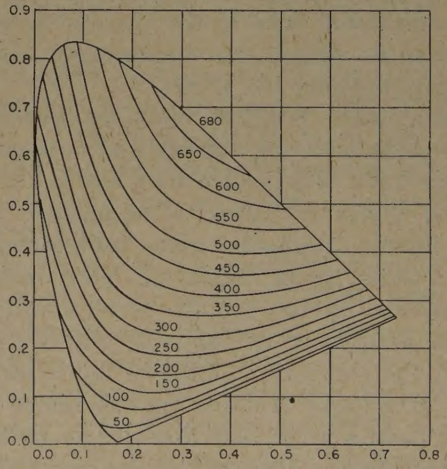

Fig. 3—Maximum luminous efficiencies of various chromaticities.

Fig. 3 illustrates the general usefulness of the chromaticity diagram. On this is represented the maximum possible luminous efficiency of light of any desired chromaticity.[8] The maximum efficiency possible under any circumstances is 680 lumens per radiated watt. This maximum is obtained only by confining the radiated energy to a narrow band of wavelengths within a few millimicrons of 555 $m\mu$. The maximum possible luminous efficiency for the chromaticity of daylight ($x=0.31$, $y=0.316$) is about 400 lumens per watt. This efficiency is not attained by natural daylight, nor by any existing lamps. It can be obtained only by use of a source whose spectrum is confined to two spectrum lines, at wavelengths of 448 and 568.7 $m\mu$. Such a source

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[5] D. L. MacAdam, "The fundamentals of color measurement," *Jour. SMPE*, vol. 31, pp. 343–348; October, 1938.

[6] Committee on Colorimetry, L. A. Jones, Chairman, "Quantitative data and methods for colorimetry," *Jour. Opt. Soc. Amer.*, vol. 34, pp. 633–688; November, 1944.

[7] A "blackbody" is a source which radiates energy in accordance with Planck's formula.

[8] D. L. MacAdam, "Maximum attainable luminous efficiency of various chromaticities," *Jour. Opt. Soc. Amer.*, vol. 40, p. 120; February, 1950.

would be very objectionable as a practical illuminant, because it would seriously distort the normal colors of objects, and the chromatic aberration of the eye would cause most objects illuminated with it to be seen surrounded by a violet haze. But the efficiency of that source is useful as a known goal that may be approached, but never exceeded, by a source having the chromaticity of daylight. Similarly, the efficiency indicated in Fig. 3 for any other chromaticity is a standard of comparison showing the amount of possible improvement in any practical case. It is interesting to note that, for almost all chromaticities, the maximum efficiency is obtained by adding 448 mμ to a second wavelength. This indicates, also, that the closer the blue primary approaches 448 mμ, the greater will be the luminous efficiencies of the chromaticities produced by additive combination of three primaries.

Similar diagrams showing the maximum possible luminous transmittances of filters having various chromaticities with daylight and tungsten light have been published.[9] From such data, Bingley[10] has computed the luminosities of two different sets of additive primaries required to reproduce the colors of the most efficient filters. Since the maximum efficiency has been closely approached only in the cases of a few yellow, orange, and red filters, the requirements computed by Bingley are probably too severe.

The maximum possible luminous reflectances of colored materials having two per cent minimum surface reflectance have been shown by Clarkson and Vickerstaff[11] for tungsten lamp illumination. They also showed limits attainable with contemporary dyes. Probably those limits would be more realistic than the theoretical limits, for the determination of the maximum luminosity demands of additive primaries. However, the theoretical limits of luminous transmittance of filters, and of luminous reflectance of colored materials having irreducible first-surface reflectance indicate the ultimate. The derivations on which they are based indicate the spectral characteristics that must be employed to attain the ultimate. Any other spectral characteristics necessarily produce lower luminous transmittance or luminous reflectance for any prescribed chromaticity.

The capabilities of a set of primaries may be shown in the manner indicated in Fig. 4, which, for some purposes, may be more informative than the diagrams that Bingley published. Fig. 4 shows, for his *C* set of primaries, the maximum luminance with which any chromaticity can be produced, relative to white. It is assumed that the maximum usable intensity of each primary is used to produce white. Fig. 5 shows the corresponding diagram for the *A* set of primaries. Fig. 6 presents a comparison of the chromaticity and luminance limits of these two sets of primaries. The lines indicating the luminosity limits in Figs. 4 and 5 may be regarded as contours of surfaces, below which are represented all colors producible by use of the corresponding set of primaries. This is illustrated in Fig. 6, which shows that the "ceiling" for the *C* primaries is above that for the *A* primaries in the green region (upper corner) and extends farther into the red, purple, and blue regions (below), but that the ceiling for the *A* primaries extends slightly farther into the bluish-green region (to the left) and is higher in the de-

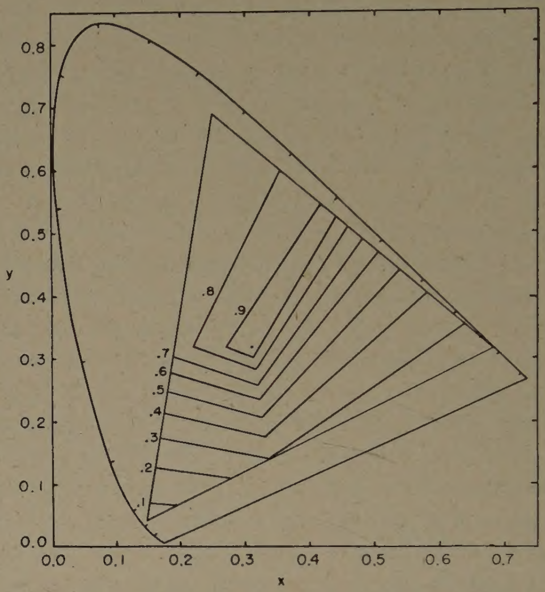

Fig. 4—Maximum luminances of various chromaticities producible by additive mixture of *C* primaries, based on assumption that maximum intensity of each is used to produce white.

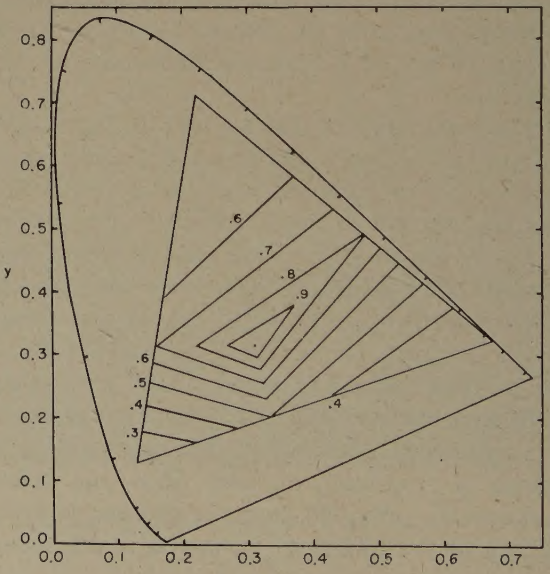

Fig. 5—Maximum luminances of various chromaticities producible by additive mixture of *A* primaries, based on same assumption as Fig. 4.

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[9] D. L. McAdam, "Maximum visual efficiency of colored materials," *Jour. Opt. Soc. Amer.*, vol. 25, pp. 361–367; November, 1935.

[10] F. J. Bingley, "Application of projective geometry to the theory of color mixture," Proc. I.R.E., vol. 36, pp. 709–723; June, 1948.

[11] M. E. Clarkson and T. Vickerstaff, "Brightness and hue of present-day dyes in relation to colour photography," *Phot. Jour.*, vol. 88B, pp. 26–39; March-April, 1948.

saturated red region (right of center) than the ceiling for the *C* primaries. The ceilings are of nearly equal height (luminance) for desaturated blues (lower left central), but the ceiling for the *C* primaries extends to much greater saturations (down to the left). It may be interesting to note that the *Order* of the Federal Communications Commission, dated October 10, 1950, specified primaries which are very nearly the same as the *A* set.

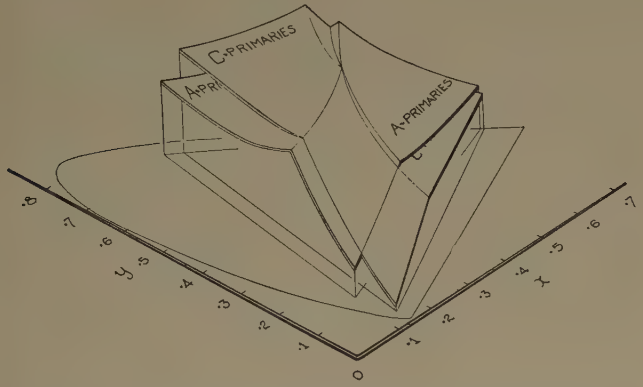

Fig. 6—Comparison of maximum luminances producible by use of primaries *A* and *C*.

The idea of a color space, suggested by this discussion, in which various luminances are represented by various heights above the chromaticity diagram, is very helpful in interpreting color measurements.

The luminance limits indicated by the contours in Figs. 4 and 5 are based on the assumption that white is the quality of the standard source, *C*, recommended by the I.C.I. As mentioned previously, this choice is arbitrary and might better be some other quality when the observers are not adapted to daylight, but the relations represented in Fig. 6 would not be altered seriously by any other reasonable choice of "white." The chromaticity gamuts indicated by the triangular boundaries in Figs. 4 and 5 are based on the assumption that a black of zero intensity can be realized and that any one of the primaries can be reduced to zero intensity, regardless of the intensities of the other primaries. The first assumption would not be applicable if any stray light from the surroundings is reflected from the screen, or if scattered light from neighboring portions of the image degrades the blacks. The second assumption would not be correct if there is any lower limit, other than zero, for the intensities of the primaries or, in the case of a field-sequential system, if the persistence of the phosphor is so great that the image for one primary contributes appreciably to the luminance of the succeeding primary. In such cases, calculations of the kind used by Clarkson and Vickerstaff for dyed materials would be required to find the actual limits of chromaticity.

Returning now from this digression, concerning the general utility of the chromaticity diagram, we summarize the possibilities and limitations of color measurements. The physical factors of color can be measured by use of spectrophotometers and spectroradiometers. The psychophysical specifications of color can be determined by use of the principle illustrated in Fig. 1. But these specifications are, so far, devoid of critical sense on which judgments of picture quality might be based. The problems remain, of discovering the proper "aim-points" for color rendering and of devising some way of evaluating discrepancies of actual color rendering from the optimum rendering.

PSYCHOPHYSICAL EVALUATION OF TONE RENDERING IN BLACK-AND-WHITE PICTURES

A great deal of work has been done, and more is in progress, for the purpose of answering the above questions for color photography. The problems are not yet solved and few partial answers can be even suggested. It seems reasonable to expect, however, that a method of investigation which appears to be fruitful in color photography may also be useful in color television. That method is an extension of the method of investigating the quality of tone reproduction, which has been found successful in the case of black-and-white photography. The method and its potentialities can probably best be appreciated if that successful application of it is reviewed.[12]

Many variables influence the quality of black-and-white photographs. One which has been studied very thoroughly is the exposure given to the negative. Study of this case is important, because it provides a functional criterion for rating the speeds of various negative materials.

A certain scene was photographed repeatedly, using exposures varying by moderate steps, ranging from definite underexposure to definite overexposure.[13] All these negatives were made on the same kind of film and were developed identically. From each negative a series of prints was made, on several grades of paper. Each negative was printed on each grade of paper with definitely more and definitely less exposure than was desirable, and with several intermediate exposures.

The complete set of prints from each negative was submitted to a number of people, working separately. Each selected from the set for each negative the print he preferred. When the selections were compared, they were found to agree remarkably well. Finally, the judges were asked to arrange the best prints from all negatives of a single scene according to tone quality.

The results in one case are shown in Fig. 7, in which the average rank of each print is plotted as a function of the exposure of the negative from which it was made. The print judged poorest by each judge was given zero rank, and successive digits were awarded to successive prints, in the order of improved quality. Beyond about the seventh print, the average rank number fluctuates inconclusively about a constant value, indicating that no significant improvement results from greater exposure of the negative. The first print A of those for which the judges could not report reproducibly any increase of quality is called the first excellent print. Similar exposure series, print selections, and quality judgments were made for many scenes of widely different types. The physical characteristics of the various negatives were measured, and compared with the judgment results.

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[12] L. A. Jones, "Recent developments in the theory and practice of tone reproduction," *Phot. Jour.*, vol. 89B, pp. 126–131; September-October, 1949.

[13] L. A. Jones, "Psychophysics and photography," *Jour. Opt. Soc. Amer.*, vol. 34, pp. 66–88; February, 1944.

The main result, the answer to the original question, is indicated in Fig. 8. This shows, in relation to the curve representing the density of the negative material as a function of exposure, the exposures used in making the first excellent print of one of the scenes. Other scenes, which had greater or less ratios of maximum-to-minimum luminance, required, of course, more or less of the exposure scale than indicated in Fig. 8. Study of the relation of the exposures used in producing the first excellent print in each case revealed that the minimum exposure should be that for which the slope of the D-versus-log E curve is 30 per cent of the average slope of the portion of the curve used for the average picture. This criterion was found to predict successfully, for average conditions, the least exposure required to obtain negatives from which excellent prints can be made. It has been made the basis for the American Standard method for determining photographic speed and speed number.[14] It was not derived from purely physical principles, nor could it have been. Picture judgments, considered together with the sensitometric measurements indicated in Fig. 8, were necessary for the establishment of this criterion.

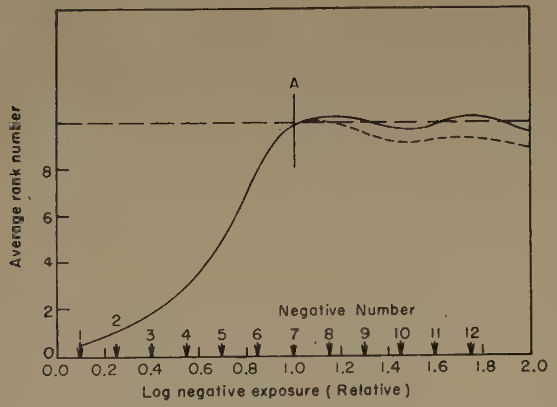

Fig. 7—Approximate relationship between print quality and negative exposure.

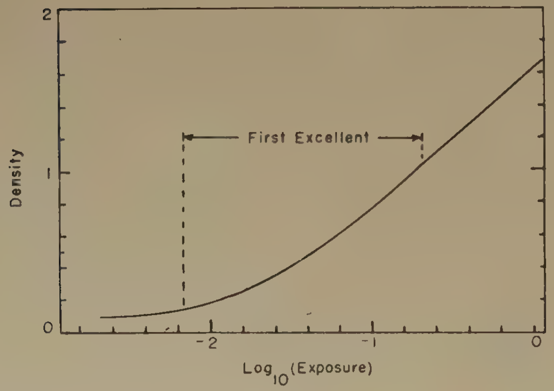

Fig. 8—Sensitometric curve of negative material, and exposures used in making first excellent print.

Similar judgments, considered in relation to physical measurements of picture characteristics, are doubtless necessary for the determination of important production variables, and ultimately of indices of reproduction quality in both color photography and color television.

However, an index of quality of color reproduction cannot be expected as one of the first results of such a program of research. No such index has yet been established for black-and-white tone reproduction. On the other hand, the earlier and more direct results which indicate optimum adjustments of production variables are at least as valuable as would be an index of quality. Such an index is of little more than academic interest when the optimum method of reproduction is known and used.

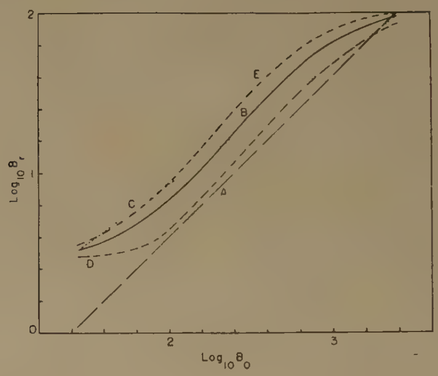

Fig. 9—Tone reproduction curves: A, "exact reproduction"; B, optimum attainable with semimatte paper; C, proportional reduction of luminance contrasts to fit density range of semimatte paper; D, tone reproduction suitable for scene in which highlights are predominant; E, tone reproduction suitable when only shadow details are important.

Another part of the study of black-and-white tone reproduction should be mentioned here, because a similar problem and outcome may be expected in color photography and color television. The straight line A, inclined at 45 degrees in Fig. 9, indicates exact objective reproduction of the luminances B_0 of a scene, in which the ratio of maximum to minimum luminance is 100. The luminances of both the scene and the reproduction are shown on logarithmic scales. Curve B shows the tone reproduction obtained for that scene by using good photographic techniques. This curve shows the luminances in a picture printed on a semimatte paper. It is apparent that the ratio of maximum to minimum luminances in this print is considerably less than the luminance ratio in the original scene. Consequently, at least some of the luminance contrasts, $\Delta B/B$, in the original scene must be decreased in the print. It might be presumed that the best compromise would be to decrease all luminance contrasts in the same proportion. Such reproduction is represented in the logarithmic plot in Fig. 9 by the straight line *C*. Curve *B*, which represents a print of very good photographic quality, does not follow this straight line. Slopes lower than 45 degrees indicate reduction of luminance contrast in the corresponding range of luminances. It is evident that reduction of contrast is greatest in the highlights and shadows, while the middletone contrasts are nearly the same as those in the original scene.

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[14] American Standards Association, "Standard Method for Determining Photographic Speed and Speed Number, Z38.2.1," New York, N. Y.; 1946.

It is interesting to note that photographic limitations are not entirely responsible for the discrepancy between objective reproduction and preferred reproduction.[15] According to Jones,[16] "there are many cases where we know that the perfect objective reproduction, although obtainable, is not the one the majority of judges will choose as of best photographic quality." This effect is real and significant in magnitude. It must be taken into account if the best quality of reproduction is to be obtained. It may be due to subjective as well as objective differences between the situations within which pictures and real scenes are observed. Only a few types of conceivable differences need be mentioned: surroundings, restrictions of field of view, modes of perception (of flat pictures rather than real objects), attitudes, emotions, and desires. Jones has shown that the differences of visual sensitivity to luminous contrast, caused by quite different conditions of adaptation when viewing the print than when viewing the original scene, must also be taken into consideration.[12] Even if we could account for the effect, we could not neglect it, nor assume that objective reproduction is preferable to any other.

The fact that the print corresponding to Curve *B* is superior to Curves *D* and *E* could not have been determined from the curves alone, nor from any other representation of the results of purely physical measurements of the prints and the original scene. The best print was chosen by inspection, and rules for judging quality of reproduction from curves such as Fig. 9, or from curves showing the compression or expansion of contrasts can be established only by comparing the results of print judgments with the curves. Such rules are therefore psychophysical.

Without psychophysical relationships, the results of optical measurements tell little about the quality of tone reproduction. Such relationships must be rather complex, because curves similar to *D* in Fig. 9 represent optimum reproductions of some scenes, in which all the important details are of high brightness, such as open beach, desert, or snowy landscapes. Likewise, prints with curves similar to *E* are best for subjects in which all the important objects are dark. In a qualitative sense, it appears that the objectionability of the compression of luminance contrasts should be weighted by some measure of the importance of various parts of the luminance scale in reproducing each particular scene.

INVESTIGATION OF QUALITY OF COLOR REPRODUCTION

The quality of photographic color reproduction is being studied by a method based on the same principles as were used in the investigation of tone reproduction in black-and-white photography. Series of pictures of a single scene are made with systematic changes of production variables. These pictures are then submitted to a large number of judges, working separately. Measurements are made of all optical quantities that seem relevant. The data from several scenes of different types are used to search for general correspondences between the judged quality of the reproductions and the optical specifications.

The investigation of color photography is much more complicated than that of black-and-white photography, because of the greater number of production variables as well as the greater variety of perceptions. The number of noticeably different tones in a monochrome picture is of the order of a few hundred, while the number of noticeably different colors (including all distinguishable tones of each chromaticity[17]) in a color photograph may be several million. This enormous increase arises from the fact that color photography deals with three independent variables, whereas monochrome reproduction involves only one. The number of distinguishable possibilities in color photography is of the order of the cube of the number in monochrome photography. It is somewhat less than the cube, because not all combinations of the three variables are possible, and variations are not equally noticeable in each of the three variables, nor independent of the values of the others.

Good tone reproduction is just as important in color photography as in black and white, but its control and measurement are considerably more complicated. Similarly, the other two variables of color which may be specified by chromaticity are much more complex to control and measure than was the single variable, luminance, in monochrome reproduction.

Some of these complications, especially those of production control, are peculiar to subtractive color photography, in which the optical primaries cannot be modulated independently of each other. Each of the three dyes, which are superimposed to make the picture, absorbs two or even three of the primaries.[18,19] In this respect, at least, color television should be less complex to control and measure than color photography.

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[15] R. M. Evans, "Introduction to Color," John Wiley and Sons, Inc., New York, N. Y.; 1947.

[16] L. A. Jones, "The psychophysical evaluation of the quality of photographic reproductions," *PSA Jour.*, 1951 (in press).

[17] D. L. MacAdam, "Note on the number of distinct chromaticities," *Jour. Opt. Soc. Amer.*, vol. 37, pp. 308–309; April, 1947.

The desire to separate the problem of evaluating the quality of color reproduction into two parts, tone reproduction and chromaticity reproduction, is understandable. If successful, it would greatly simplify the questions. But the possibility should not be taken for granted. The problem is not merely simplified; it is changed, and perhaps changed so as to have little relevance to practical color reproduction. Having recognized this danger, we can proceed to examine two attempts that have been made to evaluate color reproduction, both of which have been based on this subdivision of the problem.

In Annex *E* of the Condon report,[1] Judd, Plaza, and Balcom assumed that optimum tone reproduction requires the luminances in the reproduction to be proportional to the luminances in the original scene. For their "index of color fidelity," they took the factor of proportionality to be such that white was perfectly reproduced. They then evaluated the errors of reproduction of the luminances of other colors by subtracting the corresponding Munsell values in the original scene and in the reproduction. Munsell values specify perceptually equal tone differences by equal numerical differences. The method of Judd, Plaza, and Balcom[1] heavily penalizes distortions of the ratios of greatly different luminances, which tone reproduction studies have shown to be relatively unimportant, and disregards compressions of luminance contrasts ($\Delta B/B$) which have been found very objectionable, especially in particular portions of the tonal scale that are important in the portrayal of the subject.

After considering many conceivable ways of evaluating the quality of tone reproduction in monochrome pictures, Jones[13] has tentatively suggested that it should be evaluated in terms of departures of luminance gradients from the optimum possible with available materials, rather than in terms of discrepancies of densities (or, presumably, Munsell values) from the densities of the optimum possible reproduction. The enormous amount of data he obtained on the optimum possible tone reproductions of several hundred scenes have not been studied completely, and no final conclusions can yet be announced. It appears that the gradient should be approximately unity (that is, luminance contrast, $\Delta B/B$, should be reproduced practically unchanged) in the central portion of the tonal scale.[12] In other portions of the tonal scale, the amount of the reduction of the gradient (and therefore of luminance contrast) that can be tolerated seems to be related inversely to the importance of such tones and contrasts in the picture.[16] These compressions are optimum in the sense that they make possible the best use of the characteristics of the printing paper, which are dominated by limited density scale and nonlinear characteristic curves of the photographic materials. The key idea in this discussion, the relative importance of contrasts in various portions of the tone scale, is as yet undefined. A suitable definition will have to be operational, in terms of how "importance" is to be evaluated, based on psychophysical studies of the results of judgments of scenes.

No definition of optimum quality, nor rule for evaluating particular reproductions, can be significant or useful, no matter how simple, unless it takes into account the ultimate limitations of the process and psychophysical correlations based on quality judgments of various compromises designed to get the most satisfactory reproductions within those limitations. The fundamental question is, "What is the best that can be done under the circumstances?" Like the maximum luminous efficiency (Fig. 3) of sources and maximum luminous transmittances of filters, the answer to this problem will probably include a specification of how to get the best reproduction. That will necessarily specify some such tone reproduction curve as *B* in Fig. 9. To use any other curve, such as *A* or *C*, will result in poorer reproduction. The first will fail because it ignores the circumstance of limited luminance ratio of the paper (or screen, or television tube). The second will fail because it adopts too naive a compromise, excessively reducing important contrasts for the sake of equally prominent reproduction of unimportant contrasts. Finally, any realistic measure of the quality of reproduction will be based on the smallness of departures of slight contrasts from those of the "best" reproduction, rather than on departures of density (or Munsell value) from ideal or exact reproduction, such as was assumed by Judd, Plaza, and Balcom.[1]

Like tone reproduction, chromaticity reproduction can be evaluated in terms of discrepancies from the norm. Again, two problems are involved: How to identify the norm, "the best that can be done under the circumstances?" How to measure discrepancies of any actual reproduction from the norm so as to yield a useful figure of merit?

Judd, Plaza, and Balcom[1] assumed that exact colorimetric reproduction was the norm, and measured the discrepancies in Munsell units of hue and chroma. Hue is the term used for the characteristic of color sensation according to which red is most distinctively different from green. Munsell hue is a conventional psychophysical evaluation of hue. Chroma refers to the characteristic which differentiates highly saturated or pure colors from colors of the same hue that are desaturated, for example, by dilution with white or gray. To a fair approximation, if chroma is constant, Munsell hue differences of one unit are equally noticeable, regardless of the particular hues. One unit of Munsell hue difference is approximately twice as noticeable at ten units of

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[18] D. L. MacAdam, "Subtractive color mixture and color photography," *Jour. Opt. Soc. Amer.*, vol. 28, pp. 466–480; December, 1938.

[19] D. L. MacAdam, "Physics in color photography," *Jour. Appl. Phys.*, vol. 11, pp. 46–55; January, 1940.

chroma as at five units of chroma, and others in proportion to chroma. The complete one-hundred-step hue scale at constant chroma can be represented by a circle, (Fig. 10) and the chroma scales for various hues as radii from gray at the center. Since the metrics of this "color map" are approximately Euclidean, one hue step at ten units of chroma is only slightly more noticeable than one half a chroma step. However, Judd, Plaza, and Balcom[1] considered hue errors about four times as objectionable as equally noticeable chroma errors. In their evaluation of the seriousness of chromaticity errors, therefore, they penalized various reproductions as much for unit errors of Munsell hue at chroma 10 as for two-unit chroma errors. They did not consider that errors in some hues, such as bluish-green and purples, are much less objectionable than equally noticeable errors of hues of human skin and other familiar materials.

Having weighted all the hue and chroma errors according to the principle described above, they averaged them. In effect, this implies that all equally satisfactory reproductions of the chromaticity *C* in Fig. 10 are represented by points on a diamond-shaped boundary, such as shown in Fig. 10. It also implies that ten small errors are as serious as one error ten times their average, thus repudiating the conventional least-squares principle for minimizing errors. This procedure also ignores the common finding that errors all in one direction are less objectionable than equally great errors in diverse directions.

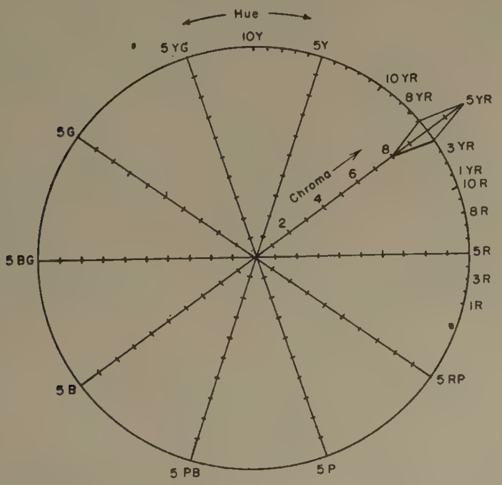

Fig. 10—Diagrammatic representation of Munsell hue circuit at 10 chroma, principal chroma scales and boundary of equally satisfactory reproductions of hue, YR; chroma, 10, according to formula of Judd, Plaza, and Balcom.

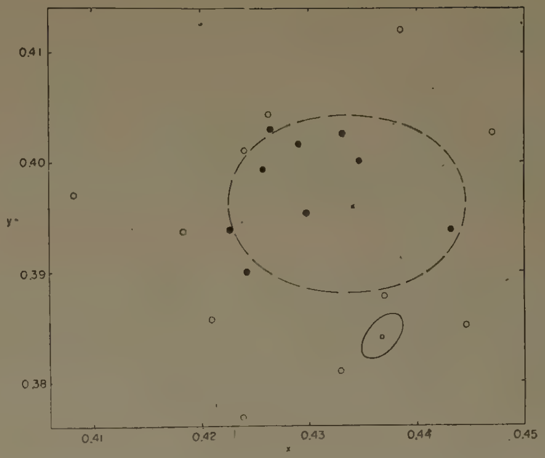

Fig. 11—Chromaticities of forehead of original subject (square), of best reproduction (cross), of reproductions accepted by 50 per cent or more judges (solid dots), and of reproductions accepted by less than 50 per cent of judges (open circles). These chromaticities are based on the assumption of a 4000° K blackbody source of illumination. Broken curve indicates an estimate of the region of 50 per cent or greater acceptance. The ellipse represents chromaticities just noticeably different from that of the subject's forehead.

Series of color prints have been made from well-exposed color-separation negatives of several typical scenes. The prints of each of these series differ in tone reproduction, balance, and in other ways subject to controlled variation. These series have been presented to numerous judges, and their judgments have been compared with results of measurements of various colors in the prints. The various points in Fig. 11 represent the chromaticities of a spot on the forehead of a portrait of a young lady, as reproduced in a number of prints, which exhibit variations of balance from too red or yellow to too blue, and from too green to too pink. Sufficiently small steps of variation were used so as to obtain a number of satisfactory prints. These prints were submitted to a number of judges who were asked to accept or reject each on the basis of balance alone. The print accepted by the most judges (83 per cent) had the forehead color shown by the cross. The solid dots represent the forehead colors in prints having 50 per cent or greater acceptance, and the open circles show the forehead colors in prints accepted by less than half the observers.

The broken curve in Fig. 11 encloses the probable zone of 50 per cent or greater acceptance. The square below this zone represents the actual color of the girl's forehead, and all points on the ellipse drawn around it represent colors all equally noticeably different from the actual skin color.

Two conclusions are indicated by the diagram in Fig. 11. First, optimum reproduction of skin color is not "exact" reproduction. The print represented by the point closest to the square ("exact reproduction") is rejected almost unanimously as "beefy." On the other hand, when the print of highest acceptance is masked and compared with the original subject, it seems quite pale.

In the second place, the shape of the 50 per cent acceptance zone is similar to the shape of the zone of equally noticeable differences. This finding does not support the decision of Judd, Plaza, and Balcom,[1] who assumed four times greater tolerance for chroma errors than for equally noticeable hue errors. Approximately horizontal radii of the 50 per cent acceptance zone and of the equal-noticeability ellipse represent chroma differences. Vertical radii indicate hue differences.

The discrepancy between "exact" reproduction and preferred reproduction is partly due to distortions inherent in the process, such that a certain discrepancy of a particular color is necessary to permit the best overall reproduction of all colors in the picture. But, as discussed in the case of monochrome reproduction, it must also be due to differences of the conditions of observation, or of the observer and his attitudes when observing pictures and when observing real objects. Certainly, no such discrepancies should be introduced by a picture window in your living room, nor by a mirror in your dressing room. In such a case, we usually consider that we are looking at the "real thing." Perhaps the farther we get from that attitude, the greater the discrepancy becomes. Perhaps wishful thinking is partly responsible, with or without the acquiescence of fading memory. Certainly, differences of adaptation must play some part, but, for the ordinary range of adapting conditions when viewing scenes and pictures, this cannot account for more than a small fraction of the discrepancy shown in Fig. 11. Whatever the causes, the discrepancy is real, and is typical of the conditions under which photographic portraits are viewed. Since similar distortions and conditions of observation are customary with motion pictures and television, similar discrepancies are likely to be necessary for best results with those media. Face colors in 25 portraits of exhibition quality have been measured. Ten of these were made with the Kodak Flexichrome Process, in which every color is completely and separately under the control of the artist, so that no compromises are necessitated by chromatic distortions of the process. Three others were pastel portraits of children by two professional artists, and two were oil paintings by a prominent contemporary artist. The original subjects were not available for spectrophotometric measurement, but the foreheads of twelve more young people were measured, in order to establish the approximate range of face colors. The range of face colors in the portraits was entirely separate from the range of natural face colors, and the separation of the centers of those ranges is approximately the same as indicated in Fig. 11. Therefore, it seems to be not only quixotic but fallacious to assume exact reproduction to be the norm, or to measure degradations from that basis.

Similar results have been obtained with other colors. Fig. 11 should not be regarded as anything other than indicative of the general nature of the results. The directions and amounts of difference between exact reproduction and optimum reproduction are different for every color tested. They must also be different, even for a single color, for processes with essentially different limitations and unavoidable distortions.

Although the 50 per cent acceptance boundary has not exactly the same shape or orientation as the ellipse of equal noticeability in Fig. 11, assumption of such a similarity would be a fair first approximation, and use of this assumption for the general case is suggested until direct determinations are made of the 50 per cent acceptance boundaries for other representative colors. Equal-noticeability ellipses found in a recent investigation[20] are shown in Fig. 12. Ellipses inferred from these have been specified for all locations in the chromaticity diagram by use of the three quantities, g_{11}, $2g_{12}$, g_{22}, shown by the contour diagrams in Figs. 13 to 15.[21]

The equal-noticeability ellipse centered on any point x, y in the chromaticity diagram is defined by the equation

$$g_{11}\Delta x^2 + 2g_{12}\Delta x\Delta y + g_{22}\Delta y^2 = 1. \qquad (1)$$

The angle θ which the major axis makes with the horizontal axis is given by

$$\tan 2\theta = 2g_{12}/(g_{11} - g_{22}). \qquad (2)$$

The value of 2θ is to be chosen from the first two quadrants (so as to make θ less than 90°) when $2g_{12}$ is negative. When $2g_{12}$ is positive, θ is greater than 90°, and therefore 2θ should be chosen from the third or fourth quadrants, depending on the sign of $\tan 2\theta$.

Half the length of the major axis of the equal-noticeability ellipse is given by

$$a = (g_{22} + g_{12}\cot\theta)^{-1/2}; \qquad (3)$$

and half the length of the minor axis is given by

$$b = (g_{11} - g_{12}\cot\theta)^{-1/2}. \qquad (4)$$

Any chromaticity difference, Δx, Δy, that is likely to be encountered as an error in color reproduction by a reasonably satisfactory process may be specified as a multiple (e) of the arbitrary unit of equal noticeability represented by the ellipses in Figs. 11 and 12 by use of the formula

$$e = (g_{11}\Delta x^2 + 2g_{12}\Delta x\Delta y + g_{22}\Delta y^2)^{1/2}. \qquad (5)$$

Silberstein[22] and MacAdam[17] have shown how to use such data as are represented by Figs. 13 to 15 to compute the number of just-noticeably different chromaticities represented by any area of the chromaticity diagram. Symbolically, this number is proportional to the surface integral

$$\int_S (g_{11}g_{22} - g_{12}^2)^{1/2}dxdy.$$

For the triangular gamut of the C set of primaries, shown in Fig. 4, the number of just-noticeably different chromaticities is about five thousand. For the A set, whose gamut is shown in Fig. 5, the number of just-noticeably different chromaticities is about three thousand. These numbers may be compared with seventeen thousand, an estimate of the total number of just-noticeably different chromaticities, up to and including spectrally pure colors.[17]

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[20] D. L. MacAdam, "Visual sensitivities to color differences in daylight," *Jour. Opt. Soc. Amer.*, vol. 32, pp. 247–274; May, 1942.

[21] D. L. MacAdam, "Specification of small chromaticity differences," *Jour. Opt. Soc. Amer.*, vol. 33, pp. 18–26; January, 1943.

[22] L. Silberstein, "Investigations on the intrinsic properties of the color domain, II," *Jour. Opt. Soc. Amer.*, vol. 33, pp. 1–10; January, 1943.

It is conceivable that some such formula as (5) may be useful for expressing results of the kind shown in Fig. 11. For this purpose, two modifications would be essential: first, to compute the deviations Δx, Δy, from the geometric center of the 50 per cent acceptance boundary and, second, to modify the values of the metric coefficients g_{11}, $2g_{12}$, g_{22} in accordance with the differences of size, shape, and orientation of the acceptance boundary and the ellipse of equal noticeability. The centers of the acceptance boundaries, and also their shapes, specified by g_{11}', $2g_{12}'$, g_{22}', may be expected to differ from process to process and for various classes of observing conditions. Thus, different kinds of distortions of the relations of reproduced colors, and various interac-

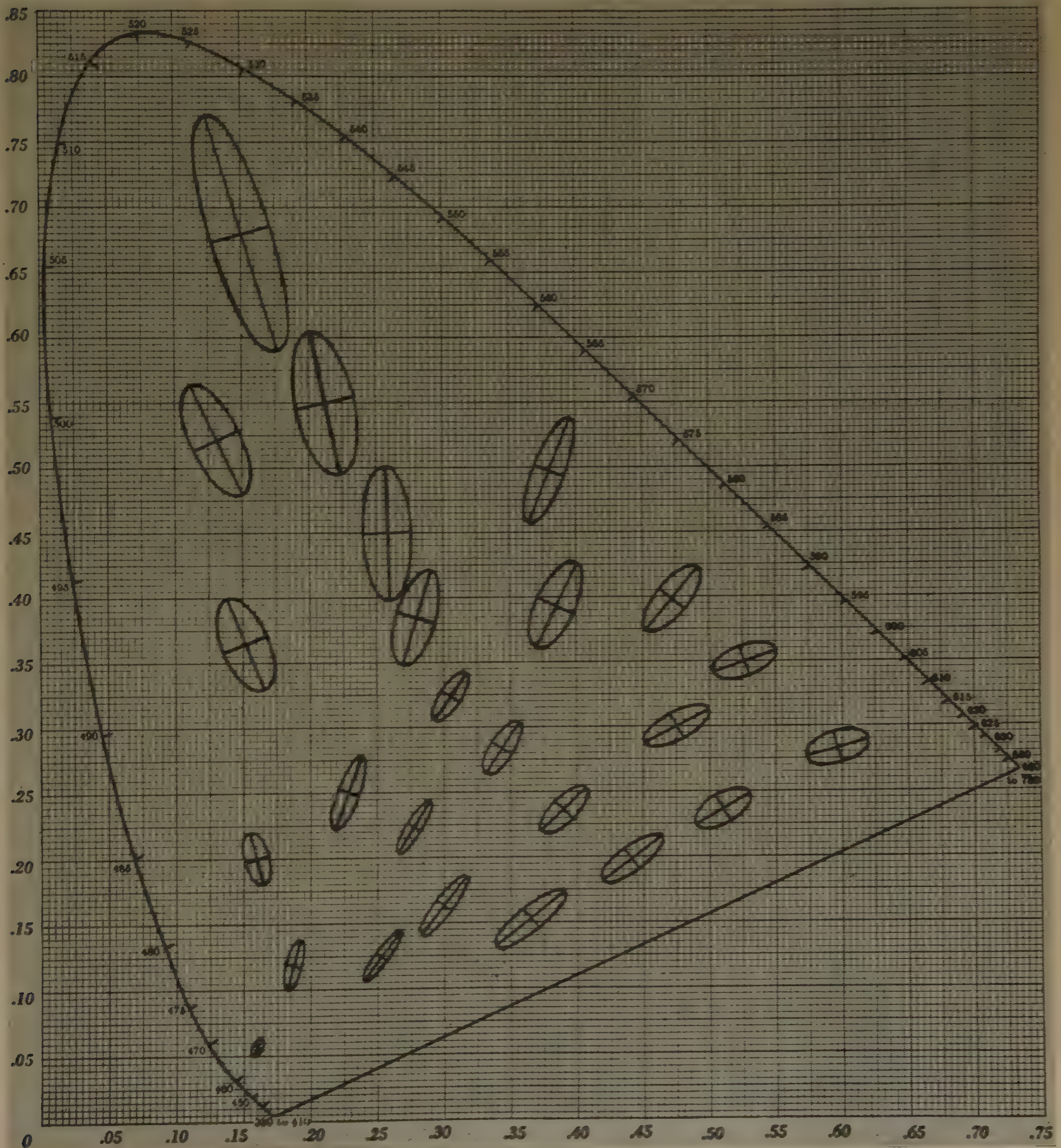

Fig. 12—Equally-noticeable chromaticity differences, represented by radii of ellipses centered on typical colors. These radii are actually ten times the standard deviation of color matching in a certain colorimeter. Under favorable conditions, color differences equal to one tenth of these radii are just noticeably different.

tions of the production variables, such as the mutual interference of functions of the dyes in subtractive processes, mentioned previously, can be expected to result in different centers and shapes of the acceptance boundaries. Similarly, various angular subtenses of the picture from the point of view of the observer, and various distributions of light in the surroundings can be expected to call for variations of the centers and the shapes of the acceptance boundaries. Such must also result from various types of interest, for example, casual, as in the case of variety shows; or intent on details, such as the color of the shirt of a jockey in a horse race; or professional, such as close-ups of surgery.

It is conceivable that results of statistical studies of the reproductions of a number of colors can be combined by use of terms of this form. The root-mean-square error of reproduction might, for example, be computed by

$$E = \left[\sum_{i=1}^{i=n} (g_{11}'\Delta x^2 + 2g_{12}'\Delta x\Delta y + g_{22}'\Delta y^2)_i/n \right]^{1/2}. \quad (6)$$

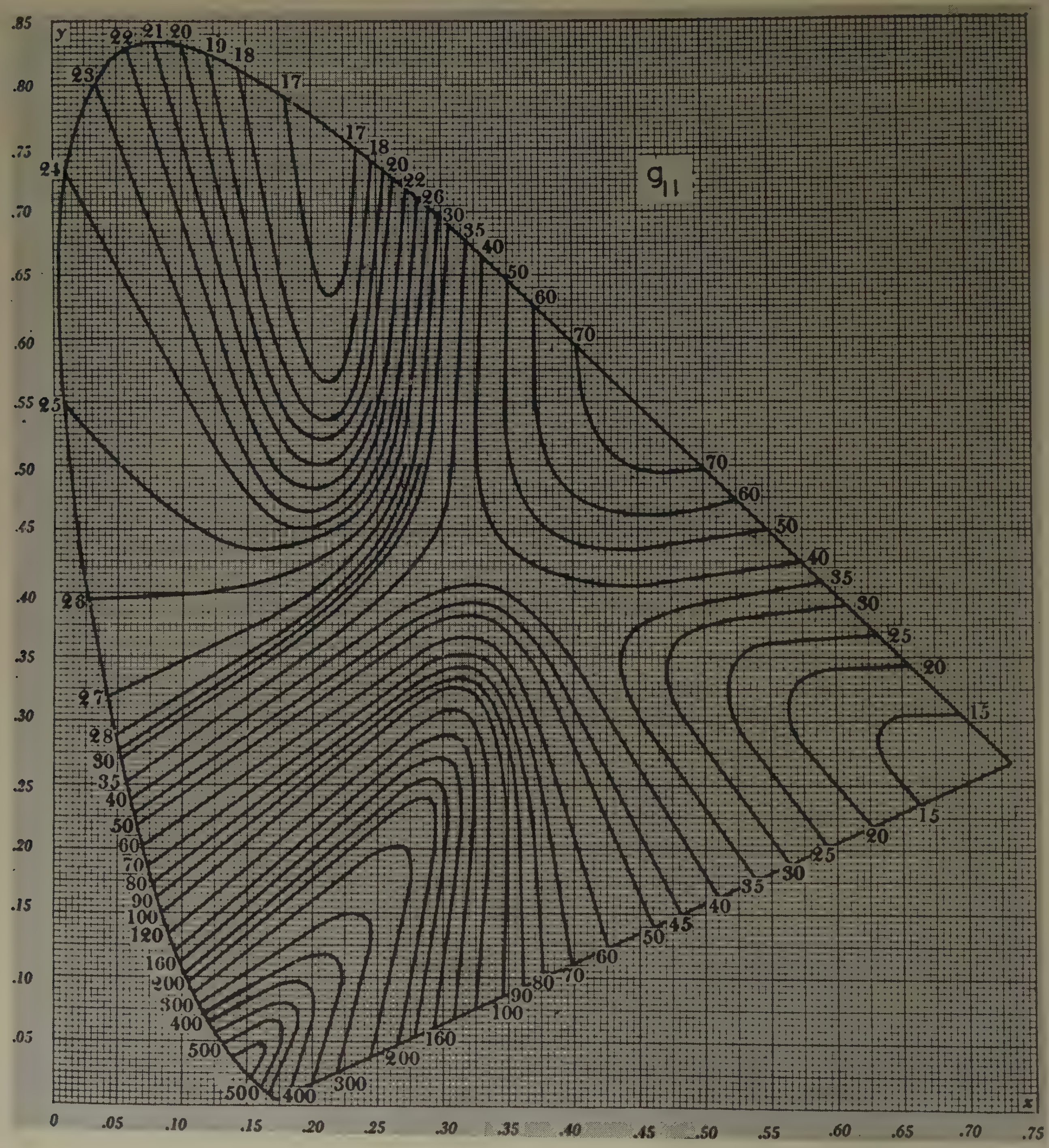

Fig. 13—Distribution of values of first metric coefficient in (5) for noticeability of chromaticity differences. Numerical values shown should all be multiplied by 10^4.

Adjustment of a process to reduce E to the smallest value employs the customary principle of least-squares adjustment.

In order to use such a formula to obtain a figure of merit for chromaticity reproduction, the optimum reproductions (that is, the centers of the 50 per cent acceptance boundaries) will have to be determined for a number of colors that are typical and important in color pictures. The sizes and shapes of the acceptance boundaries will also be found during that psychophysical analysis, thus indicating the required modifications g_{11}', $2g_{12}'$, g_{22}' of the metric coefficients.

Having considered the separated problems of how to evaluate departures from optimum tone reproduction and how to evaluate departures from optimum chromaticity reproduction, it remains to consider how we can combine such results so as to evaluate departures from optimum color reproduction, which almost invariably

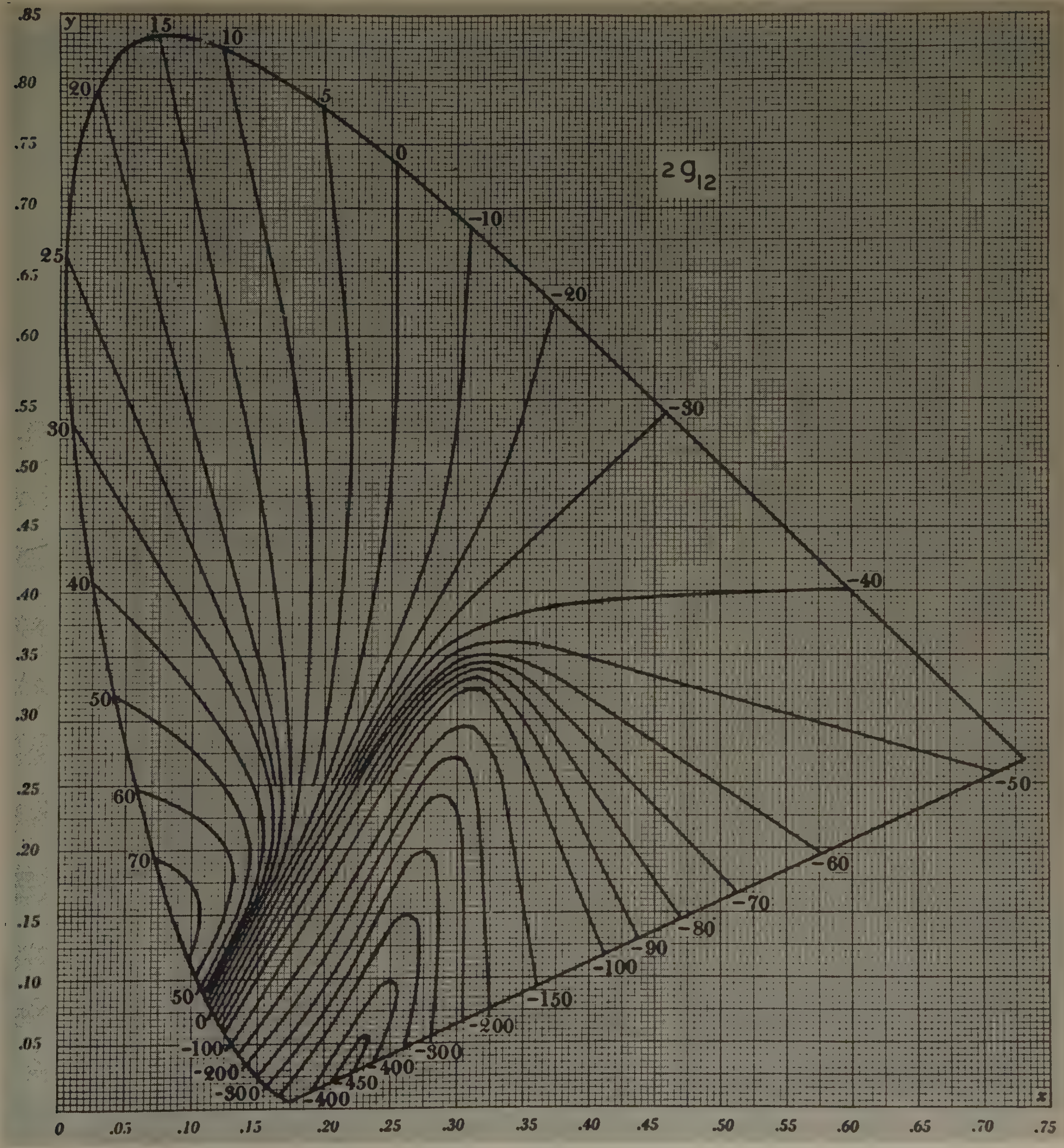

Fig. 14—Distribution of values of second metric coefficient in (5) for noticeability of chromaticity differences. Numerical values shown should all be multiplied by 10^4.

consist of errors of both tone and chromaticity reproduction.

Judd, Plaza, and Balcom[1] assumed that such errors could be weighted by their relative importance and simply averaged. They decided that one Munsell value step is as important in a color picture as two Munsell chroma steps, and they assigned relative weights to discrepancies from "exact" tone and chromaticity reproduction in accordance with that conclusion. Analogous to the case of the simple addition of weighted hue and chroma "errors," this implies that an octahedral surface, having three diamond-shaped principal cross sections in the hue-chroma, hue-value, and chroma-value planes, represents all equally objectionable reproductions of a single color in the original scene.

No attempt has yet been made to combine results from the psychophysical studies of tone reproduction and chromaticity reproduction. It is conceivable that the kind of formula suggested for statistical ratings of chromaticity reproductions can be generalized, analo-

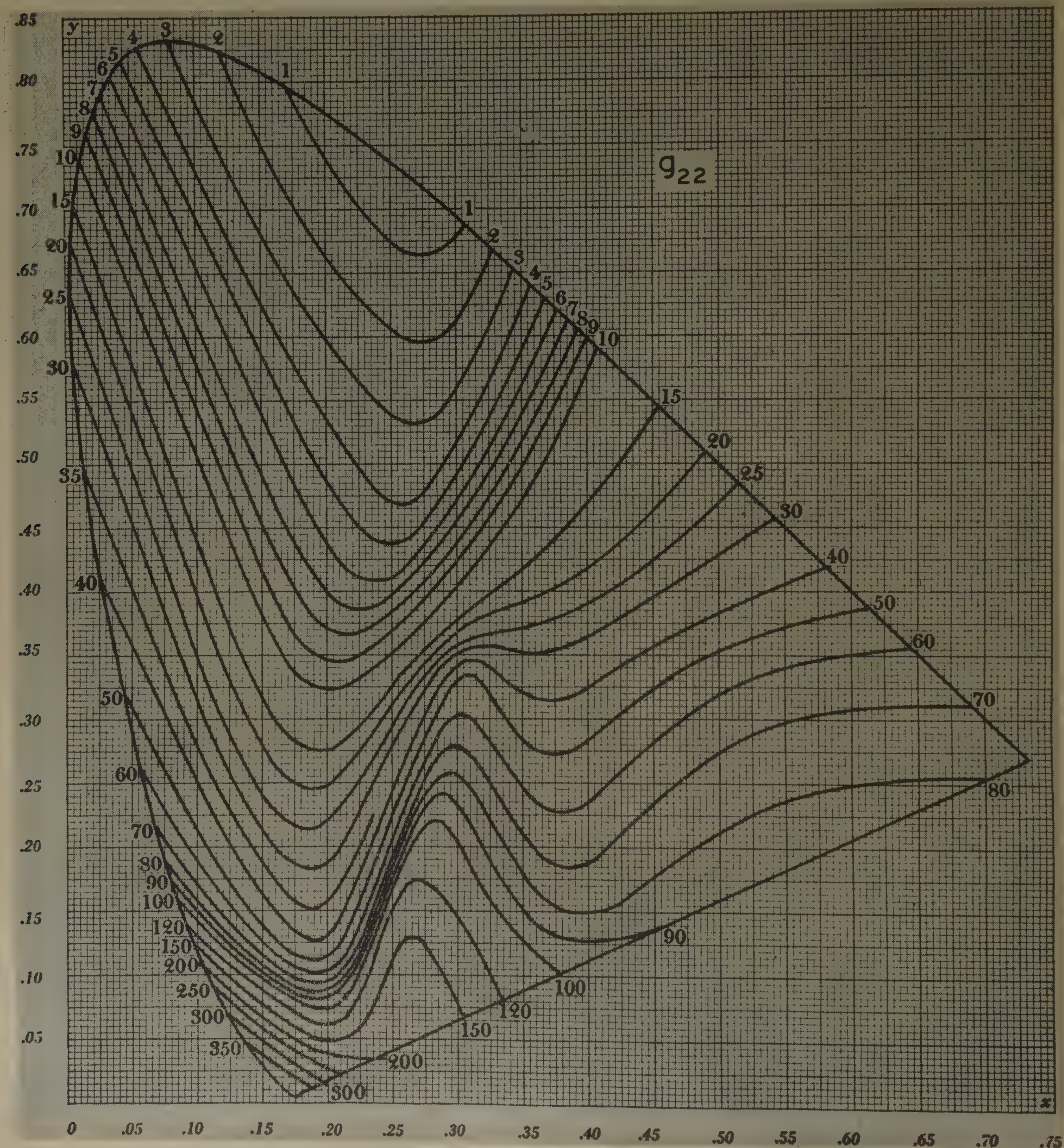

Fig. 15—Distribution of values of third metric coefficient in (5) for noticeability of chromaticity differences. Numerical values shown should all be multiplied by 10^4.

gously to the way in which the original formula for the noticeability of equiluminous chromaticity differences has been generalized to measure the noticeability of combined luminance and chromaticity differences.[23] The latter extension was accomplished by adding three terms to the simpler formula:

$$e = (g_{11}\Delta x^2 + 2g_{12}\Delta x\Delta y + g_{22}\Delta y^2 + 2g_{23}\Delta y\Delta \log B + g_{33}(\Delta \log B)^2 + 2g_{13}\Delta x\Delta \log B)^{1/2}. \quad (7)$$

The values of $g_{11}, \cdots, g_{13}$ suitable for the measurement of the noticeability of color differences were published for a large number of typical colors.[23] No interpolation procedure has yet been published.

Since tone reproduction studies have shown that contrast reductions, rather than "errors" of luminance, are significant, the use of a measure of this reduction in place of $\Delta \log B$ may be more appropriate in a formula for the figure of merit of color reproduction. Luminous contrast reduction might be measured by $1-(\Delta B_r/B_r)/(\Delta B_0/B_0)$. To a good approximation, this is equal to $1-\Delta \log B_r/\Delta \log B_0$. If the slope of the reproduction curve is denoted by M_r, then $1-M_r$ represents the same approximation to the expression for luminous contrast reduction. This quantity has been studied by Jones, as the most promising measure of loss of tone reproduction.[24] If we adopt the symbol, $\Delta M=1-M_r$, then a conceivable formula with which to measure a particular error of color reproduction is

$$e' = (g_{11}'\Delta x^2 + 2g_{12}'\Delta x\Delta y + g_{22}'\Delta y^2 + 2g_{23}'\Delta y\Delta M + g_{33}'\Delta M^2 + 2g_{13}'\Delta x\Delta M)^{1/2}. \quad (8)$$

The g's in this formula may be expected to differ from those in the formula for the noticeability of color differences, because of the replacement of $\Delta \log B$ by ΔM and because the 50 per cent acceptance boundary in the chromaticity diagram (Fig. 11) is different from the ellipse of equal noticeability. It should also be noted again that Δx and Δy should be measured from the optimum reproduction, such as indicated in Fig. 11, rather than from the chromaticity of the original. It is also to be noted that the relative magnitudes of the coefficients in the first and last groups of three terms in (7) depend very much on the conditions of observation. For instance, the ratio of g_{33} to g_{11} is fifty thousand times as great when the observer's task is to read small letters that differ only slightly in color from their background, than when they are asked to rate various attempted "matches" presented in the form of uniform and nearly gray color-prints, 3 by 4 inches large, mounted on white cards with unremovable, inch-wide borders. This factor is the square of the ratio (225) of the luminance contrasts equivalent to a prescribed chromatic contrast under the two circumstances.[25]

When a number of reproduction errors are to be averaged, it will probably be necessary to weight them according to their importance. To some extent these weights will depend upon the subject matter of each picture. The color of human skin will frequently be weighted heavily, and other colors in accordance with their familiarity, emotional associations, and frequency of occurrence. Furthermore, those weights should probably depend upon the luminances of the colors, relative to the tonal range of the scene. Certainly, optimum rendering of the chromaticity as well as the luminance of the face of a person in the deeply shadowed background of a scene is less important than for the face of a person in the brightly lighted foreground. It therefore seems probable that the "importance" factors, which were first suggested in the discussion of optimum tone reproduction, should be applied not only to the terms expressive of luminous contrast reproduction, but to all terms alike. For this reason it was suggested that it is probably inadvisable to subdivide the problem of specifying quality of color reproduction into two parts, dealing separately with tone reproduction and chromaticity reproduction.

If all these conjectures are combined, a general form can be suggested for the root-mean-square error of color reproduction:

$$E = \left[\sum_{i=1}^{i=n} W_i(g_{11}'\Delta x^2 + 2g_{12}'\Delta x\Delta y + g_{22}'\Delta y^2 + 2g_{23}'\Delta y\Delta M + g_{33}'\Delta M^2 + 2g_{13}'\Delta x\Delta M)_i/n \right]^{1/2}. \quad (9)$$

For this evaluation, Δx and Δy should be measured from the optimum reproduction. The contrast reduction term,

$$\Delta M = 1 - \Delta \log B_r/\Delta \log B_0,$$

is primarily a function of B_r. Any residual dependence of ΔM on x, y is an indication of unstable balance of the system, although not necessarily a suitable measure of balance.

Judging from analogous data on noticeability of color differences, $g_{11}', \cdots, g_{13}'$ depend primarily on chromaticity for all comfortable reading levels of luminance (above about one foot-lambert). The weights, W_i, which could be combined with $g_{11}', \cdots, g_{13}'$, require separate investigation and will probably vary most markedly with luminance B_r.

A "figure of merit" for color reproduction can be derived only by adoption of some arbitrary convention. If $g_{11}', \cdots, g_{13}'$ are based on the 50 per cent acceptance boundary, as in Fig. 11, then an average error E equal to 1 means that the picture would be rejected by 50 per cent of the judges. To a first approximation, the percentage of judges who would reject a reproduction having some other value of E would be proportional to the ordinate of the probability integral, in which the usually tabulated abscissa hx is 0.477 E. Thus, for $E=2$,

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[23] W. R. J. Brown and D. L. MacAdam, "Visual sensitivities to combined chromaticity and luminance differences," *Jour. Opt. Soc. Amer.*, vol. 39, pp. 808–834; October, 1949.

[24] L. A. Jones, "The evaluation of negative film speeds in terms of print quality," *Jour. Frank. Inst.*, vol. 227, pp. 297–354, March, 1939; also pp. 497–544, April, 1939.

[25] D. L. MacAdam, "Color discrimination and the influence of color contrast on visual acuity," *Revue d'Optique*, vol. 28, pp. 161–173; March, 1949.

$hx=0.954$, and it is to be expected that the reproduction would be rejected by about 82 per cent of the judges. For $E=0.5$, it may be expected to be rejected by about 26 per cent. This direct interpretation of E is lost if a figure of merit of the form, $100(1-E/C)$, suggested by Judd, Plaza, and Balcom[1] is adopted, C being some arbitrary constant, such as 30, in the instance cited. If a figure of merit is desired, which shall be high for the most satisfactory reproductions, and low but never negative for the worst reproductions, perhaps the percentage of judges accepting the reproduction will serve. Thus, from these examples, the figure of merit corresponding to $E=1$ would be $F=50$; for $E=2$, F would be 18; and for $E=0.5$, $F=74$. For other values of E, F can be computed easily by use of any table of the probability integral.

Such an interpretation makes it evident that figures of merit cannot be combined so as to predict the quality of reproduction of a two-stage process, such as copying or televising a color photograph. The errors of reproduction of each process are vectors, which may compensate each other as well as accumulate. Furthermore, the errors are not measured from an absolute base, but from subjectively optimum reproductions. For these and many other reasons, it seems futile to hope for a figure of merit which can be multiplied, or combined in any way, to predict the quality of reproduction of combined processes. The figure of merit of a combined process can be determined only by application of the principles, and probably by use of the same formula as for direct reproduction.

RETROSPECT AND PROSPECT

The evaluation of quality of color reproduction poses many complex problems. The order in which they have been investigated is an historical accident, arising from the fact that black-and-white pictures were made first and were important long before color photographs. The additional complexity of the latter, not only the complexity of their production but the complexity of their appearance, further delayed investigations aimed at evaluating their quality.

It is by no means certain that results of tone reproduction studies of black-and-white pictures can be carried over, and merely supplemented by studies of chromaticity reproduction. Optimum reproduction needs to be identified. Since it depends upon the limitations of the reproduction process, as well as upon human vision and judgment, optimum reproduction will probably have to be determined for each process separately.

Projected photographic transparencies share many, but not all, of the limitations of television. To the extent to which their limitations are equivalent, results for one process can probably be applied to the other. Prints on paper suffer from much more severe limitations. Only the principles of investigation, not specific results, can be expected to apply to motion pictures and to television. Most of the tone reproduction studies have been made on reflection prints, and investigations of quality of color photographs is almost entirely concerned with reflection prints. Perhaps this is because the limitations of paper prints are so serious. Every effort has to be made to get the best results possible under the circumstances. However, it is only a matter of time before the limitations inherent in motion pictures and in television will force more systematic studies of reproduction quality. For this reason, this account is given of the principles of investigation which have been used in tone reproduction studies of black-and-white prints, and of the way in which the method seems to be applicable to color photography.

This program may seem elaborate, but it does not appear wise to base important decisions on less direct evidence. The investigation of color quality may be expected to be easier, quicker, and more systematic and complete in color television than in color photography, because changes in production variables can be made more easily, with continuous gradations if desirable, and reproducibly, by electronic controls. Different pictures have to be made for color photography, and photographic processing controls are less direct, less convenient to change, and less reproducible than electronic controls. Each desired change requires a long time in color photography, whereas most changes could be made subject to nearly instantaneous control in color television. The variety of tone reproduction curves (transfer curves) obtainable with television should be much greater than in photography, and a more complete and systematic search for the optimum quality of color reproduction should be possible.

The program is to vary the production controls in systematic manners, measure the resulting color reproduction in the best way known (e.g., the I.C.I. method at the present time), submit the reproductions to visual judgment, and study the judgment data in comparison with the measurements in order to find significant correlations. The growing experience of such studies of color photography is suggested as a guide. Particular studies should be made of skin colors, gray scales, and other crucial colors. If certain conditions seem to be identified as giving optimum reproduction, it would be very desirable to set them up and verify the fact, or to find exceptions which can be used to improve the concept of optimum. Deviations of measured characteristics of other reproductions should then be computed, or directly measured, from the optimum. Quality ratings, either directly reported by judges or based on the proportion of judges who accept the reproduction as satisfactory, can then be correlated with the deviations from optimum reproduction. Only in this general fashion can we establish a method for assessing various kinds of deviations and their combinations.

Preliminary estimates of optimum reproduction and of seriousness of deviations may be based tentatively on results of studies of noticeability of color differences and on fragmentary results of studies of color photography. These estimates can be improved as various parts of the program are carried out. This beginning offers a basis for growth. New results can be grafted on these roots.

The formulas shown in this account are extremely tentative. They are merely suggestive of the nature of the problem, and of conceivable forms of the solution. These may prove unnecessarily complex. They are sufficiently definite in form to guide research, and yet they are sufficiently flexible so that their accuracy can be improved with each increase of our knowledge. In this sense they symbolize a program of research, and a goal.

Conclusions

One conclusion only can be stated with assurance: that the successful index of quality of color reproduction will ultimately be established as a result of psychophysical analysis of judgments of picture quality, referred unambiguously to the pictures by measurements of relevant optical quantities.

Elements of Thermionics*

W. E. DANFORTH†

> The program of publication of valuable tutorial material in the PROCEEDINGS OF THE I.R.E. continues with the appearance of the paper here presented. Due to the basic nature of the subject matter herein described, this paper is, of necessity, somewhat more mathematical and theoretical than most papers to be included in the tutorial papers series. However, it is felt that the inclusion of a few such papers will, on the whole, make the series better rounded and of greater value to the readers of the PROCEEDINGS OF THE I.R.E.—*The Editor.*

Summary—**Recent review papers[1–3] in this field have provided those engaged in research on thermionic emission with critical review material of an encyclopaedic nature. This article approaches the matter from a different point of view, viz, that of the engineer or research worker in some other field who wishes to acquaint himself with the main experimental features and the principal theoretical developments of the subject. Much the greater part is devoted to the latter. An attempt is made, assuming only undergraduate mathematics, to begin with a simple formulation of statistical mechanics and proceed from there to certain relationships of landmark importance. These include the Richardson equation which is of general validity for all substances, the Schottky equation concerning effects of electric field, and the Fowler equation for emission from a normal impurity semiconductor which is the Richardson equation expressed in terms of a particular semiconductor model. Certain results of quantum mechanics are introduced where needed and no previous mastery of this subject is required.**

I. General Empirical Considerations

A. Space-Charge Limitation

THE FIRST CIRCUMSTANCE of which the reader should be reminded is that of space-charge-limited and emission-limited cathodes. In many applications, the emission actually used is much smaller than that which the cathode would be capable of supplying if higher anode voltages were applied. The electron density in the space immediately adjacent to the emitting surface limits the electron emission to a certain value. The thermionic emission in such a tube is obviously determined by geometrical design considerations. It is therefore not in the province of this paper, which concerns itself with the *ability of materials to emit electrons.*

Since, however, the thermionic emission is always measured in a tube in which space-charge limitation may be present under certain circumstances, care must be taken to insure that results are properly interpreted.

In general, the "true thermionic emission" of a given cathode surface is determined by interpretations of the curve of emission current versus the anode voltage. Two methods are commonly used for this purpose.

B. Method of Departure from the Two-Thirds Power Line

For those values of anode voltage V where the current I is space-charge-limited it can be shown from straightforward electrodynamics that

$$I = aV^{3/2} \tag{1}$$

where the constant of proportionality a can be readily computed from the dimensions. A common procedure consists in plotting $I^{2/3}$ against V, which gives a straight line passing through the origin. This relationship, however, assumes that the field at the surface of the cathode is zero which is the mathematician's way of saying that more electrons are available for emission than the existing anode voltage demands. Therefore, when the anode voltage is raised to the region where the demand for

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[*] Decimal classification: R138. Original manuscript received by the Institute, February 23, 1951; revised manuscript received, March 9, 1951.

[†] Bartol Research Foundation, Swarthmore, Pa.

[1] J. P. Blewett, "The properties of oxide coated cathodes," *Jour. Appl. Phys.*, vol. 10, p. 668–679, October, 1939; also, pp. 831–848, December, 1939.

[2] A. S. Eisenstein, "Advances in Electronics," vol. 1, p. 1, Academic Press, New York, N. Y.

[3] C. Herring and M. H. Nichols, "Thermionic emission," *Rev. Mod. Phys.*, vol. 21, p. 185; April, 1949.

electrons exceeds the supply (and a field exists at the cathode surface which tends to draw electrons away from it) the curve falls away from the straight line as shown in Fig. 1.

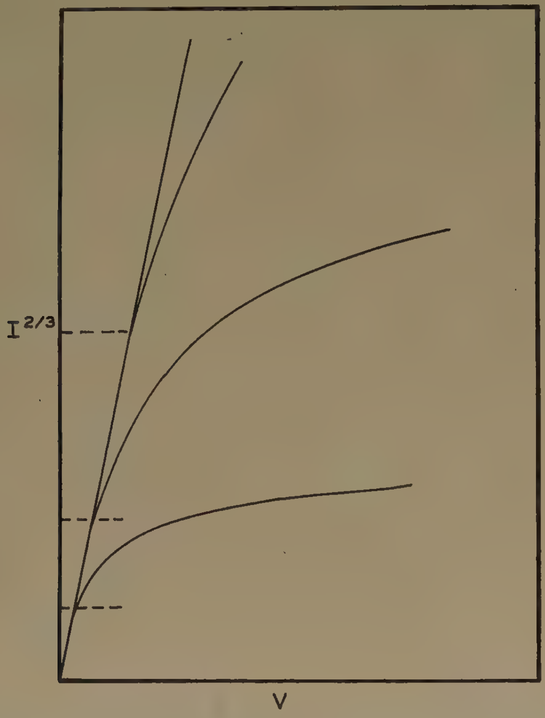

Fig. 1—The two-thirds power plot. The true thermionic emission is that value at which the curve leaves the straight line.

The value of current at the point where the curve leaves the line represents the true value of electron emission of which the surface is capable, without the help of externally applied electric fields. A disadvantage of this method lies in the uncertainty, in an experimental plot, of deciding just where the curve does leave the line. For this reason another method is generally used where precise values of emission are desired.

C. Method of Extrapolation of the High Field Equation

This method approaches the true value of emission from above, so to speak, rather than from below as is done using the two-thirds power law. High voltages, known to be above the "knee" of Fig. 1, are applied. For voltages sufficiently high to remove all space-charge effects, the current is shown theoretically, in Section II*B*, to be related to the anode voltage as follows:

$$\log I = \log I_0 + b\sqrt{V} \tag{2}$$

where I_0 is the true emission at zero field and V is the anode voltage. In Fig. 2 is shown a plot, according to (2) of actual experimental data. For high values of V the curve becomes linear and may be extrapolated back to zero V as shown by the dotted line.

This method removes the feeling of uncertainty, mentioned above, connected with the decision as to where the curve of Fig. 1 leaves the two-thirds power line. The intersection of the dotted lines of Fig. 2 with the axis of zero V yields a precise figure for I_0. One is not always sure, however, that this apparent precision, in which the uncertainties of the former method are avoided, may not be hiding other uncertainties of different natures.

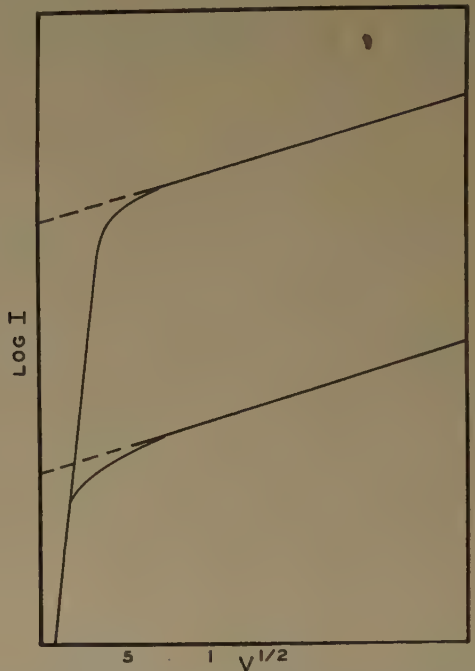

Fig. 2—The Schottky plot. The true thermionic emission is given by extrapolation of the straight line to zero voltage.

For determining thermionic constants of smooth-surfaced pure metals at low values of emission current, the extrapolation to $V=0$ yields accurate values. But in cases where complex surfaces give rise to anomalous forms of I versus V and in all cases where high currents are involved (which also, through space-charge effects, complicate the I versus V relation), the determination, to high accuracy, of the true (field-free) thermionic emission is not a simple matter.

D. Pulsed Techniques

In the case of clean metals in good vacuum the thermionic emission is an intrinsic property of the metal itself; it is independent of time, a function of temperature alone. With semiconductors, however, the emission is a sensitive function of very small quantities of "impurities" whose concentration may be altered by the very process of drawing current. Hence, in general, with this type of emitter, the emission is a function of the time following application of the anode voltage.[4]

Thus, in order to determine the true thermionic emission of a semiconductor surface which has attained equilibrium at a given temperature with no current flowing it is necessary to use oscillographic, or equivalent, techniques which determine the value of emission at the initial instant. The square microsecond pulses delivered by World War II radar "modulators" are often used for this purpose. The term "pulsed emission," which arose during the war period, means essentially the true emission of the surface, (relatively) undisturbed by the drawing of current.

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[4] For brevity, the only form of decay treated here is that due to change in the emitting power of the surface. Time effects, due to capacitative effects at a high resistance interface, which naturally must occur especially in the region of short times, are omitted because of their lack of bearing on the subject of *thermionic emission*, per se.

E. Decay and "dc"

In the period during and following the war, it was customary to hear the phrases "pulsed emission" and "dc emission" used as if they referred to more or less unrelated properties of a cathode. And it was, indeed, found that very little correlation could be said to exist, considering observations under different circumstances with a given type of semiconductor cathode, between data taken with one-microsecond pulses and "synchroscopes" on the one hand, and dc readings from ordinary meters on the other.

The situation may be expressed as follows: The true emission (undisturbed by the drawing of current) is given by measurements with widely spaced pulses of very short duration. When a constant anode voltage is applied, however, and current starts to flow continuously, various mechanisms go into action which change the condition of activation of the emitting surface, and the emission (in general) decreases with time. The rate of this decrease (referred to as "decay") and the total amount of decrease before a new equilibrium value of emission is attained, depend upon a multitude of special circumstances. Some of these concern the inner workings of the cathode material itself while many others have to do with completely extraneous matters such as constitution of the anode, its state of electron bombardment, and so forth.

After removal of the anode voltage there is, in general, a return to an equilibrium condition capable of increased emission. If a series of current-drawing periods are alternated with sufficiently long rest periods, a steady state usually occurs where, during each rest period, the emission will recover fully to its value at the beginning of the preceding current-drawing period. This phenomenon may be called "reversible decay." The occurrence of "decay" which fails to recover in a short time at the same temperature may be termed "deactivation" to distinguish it from the self-recovering phenomenon.

It is characteristic of a metal that no activation is required. Given a clean surface and a high degree of vacuum, the number of electrons emitted per second will be a function of temperature alone. Clean metals show no time variations.

Of the semiconductor emitters the BaSr oxide system is by far the most efficient source of electrons at low temperatures but is also the most critical as regards activation and sensitivity to poisoning. Between BaSr oxide and the metals in this respect is the thorium oxide system which, while requiring much higher temperatures than the former, requires very little attention to activation and is relatively insensitive to poisoning.

II. THEORETICAL DEVELOPMENTS

A. The Richardson Equation

1. General

Probably the most prominent single relation in the field of thermionics is that which concerns the variation of thermionic emission with temperature. This is known as the Richardson equation and is written in the form

$$I = AT^2 e^{-\phi/kT} \tag{3}$$

where ϕ is a quantity usually thought of as the energy required to remove an electron from the metal, k is the gas constant per molecule (Boltzmann constant), T is the absolute temperature, and A is a constant. If the constant A be regarded as arbitrary, the law is reasonably well obeyed by nearly all emitters. The objective of the material which immediately follows is to review the bases from which the equation has been derived.

There are two approaches to the problem. At first glance, the natural procedure would seem to be to consider the electrons inside the solid and calculate the number per second which bombard the surface (from within) with sufficient energy to surmount the barrier ϕ. In spite of the straightforward character of this approach, it is given a secondary place in this paper in favor of another method which, while logically more roundabout, has the advantage of a validity which is clearly independent of any assumptions regarding the inner nature of the solid. After a rather complete exposition of the latter method, which we call the outside derivation, a brief sketch of the inside derivation is given.

2. The Outside Derivation

We proceed with that treatment in which one imagines that the solid is emitting electrons into a space of finite volume, the whole system being at a uniform temperature. Equilibrium is established when the density of electrons in the space is such that the number striking the solid surface from without (per unit time) is equal to the number emitted. Thus, if means are available for computing the equilibrium density, the number emitted per second can readily be obtained by calculating, from simple kinetic theory, the rate of bombardment of the surface from outside. The necessary computation of the density outside is based on the principle that the number of particles in the space will increase to the point where the *free energy* per particle outside (calculated from theory) is equal to that of a particle inside (a constant remaining to be determined).

It is to be expected that this approach to the problem of emission of electrons into a vacuum will at first seem somewhat artificial. Admittedly the equilibrium picture has, for thermionic emission, no physical reality, and is to be regarded somewhat as a mathematical device. For ordinary evaporation, the method is without artificiality. The results obtained will apply as well to neutral molecules as to electrons.

We proceed to an outline of those statistical considerations which lead to the formula for the free energy of a gas. First, a brief digression into quantum principles is necessary.

(*a*) *Quantized energies.* In a perfect gas confined to a certain volume, whether or not the particles are thought of as charged, modern theory says that a particle may have only discrete energies. This is, of course, related to the wave nature of the particles. A single particle is represented by a standing wave between reflecting walls. Since the amplitude of the wave must be zero at the walls, only certain discrete wavelengths are allowable. Therefore, since the energy of the particle bears relation to the *wavelength* (and not to the amplitude), only discrete energy values are permitted.

One of the basic relationships of quantum mechanics is the following

$$p = \frac{h}{\lambda}, \tag{4}$$

where p is the momentum of a free particle, λ is the corresponding wavelength, and h is Planck's constant. Using this, the kinetic energy (ϵ) of a free particle may be written

$$\epsilon = \frac{1}{2m}\left(\frac{h^2}{\lambda_x^2} + \frac{h^2}{\lambda_y^2} + \frac{h^2}{\lambda_z^2}\right) \tag{5}$$

where λ_x, λ_y, and λ_z refer to wavelengths in the three co-ordinate directions, analogous to the three components of momentum. Then writing, as necessitated by the finite length l of the box (assumed cubical for convenience) $\lambda_x = 2l/K_x$ the energy becomes

$$\epsilon = \frac{h^2}{8mV^{2/3}}(K_x^2 + K_y^2 + K_z^2) \tag{6}$$

where K_x, K_y, and K_z may be any integers.

The dependence on V may be puzzling at first. Why, one asks, should the kinetic energy of a free particle depend upon the size of the box in which it is confined? Actually, it doesn't. Considering the brief derivation of (6) one sees that if V is altered, the K's must also be altered in such a way as to keep ϵ constant. (The symbol V is carried through the analysis until the point is reached where it is divided into the total number of particles, forming the number per unit volume.)

(*b*) *The energy distribution.*[5] In order to compute the free energy of N particles in the gas it is necessary to know how they are distributed in energy. We must seek, in other words, the function $f(\epsilon)$ such that $f(\epsilon)\Delta\epsilon$ is the number of particles having energies between ϵ and $\epsilon + \Delta\epsilon$. Equation (6) defines, for a given volume, a set of discrete energy levels. In order to derive the continuous function $f(\epsilon)$, it is necessary to postulate that the $\Delta\epsilon$'s are sufficiently large so that each includes a large number of the discrete energy levels.

The problem is now, given a set of energy regions, $(\Delta\epsilon)_1$, $(\Delta\epsilon)_2$, and so on, to determine the corresponding set of numbers of particles N_1, N_2, and so on, which will most probably be found in these regions. The particular set of N's which will actually be found is assumed to be that set having the largest number of internal arrangements, i.e., possible ways of occurring by chance. We therefore compute the number of internal arrangements associated with a given set of N's and then seek that particular set for which the number of arrangements is a maximum.

We first compute the number of arrangements of N_j particles in the region $(\Delta\epsilon)_j$. The total number of possible arrangements for the whole set of N's is then the product of the numbers of arrangements for the several individual regions. In computing the number of possible arrangements of electrons among energy levels we again encounter properties of electrons which are nonclassical and concerning which we accept the following quantum mechanical results:

1. No meaning can be ascribed to individuality of particles, i.e., to the interchange of two particles. Given a certain arrangement of particles among energy levels, there is no meaning in obtaining another arrangement by an interchange of energy values among the particles.
2. Only one particle can occupy a given energy level.[6]
3. Each discrete energy value defined by (6) has associated with it two energy levels; i.e., in a given system, the number of electrons which may assume a given value of energy is equal to or less than two. This is a result of considerations concerning electron spin, quantum mechanically formulated.

Now letting C_j represent the number of levels in the region $(\Delta\epsilon)_j$, the number of ways in which N_j electrons can be arranged among the C_j levels is, assuming (1) and (2) above given by

$$\frac{C_j!}{N_j!(C_j - N_j)!}. \tag{7}$$

If now Ω is the total number of arrangements possible throughout the whole set of N_j's, we have

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[5] The statistical formulation in this section utilizes in the main, the approach of J. E. Mayer and M. G. Mayer, "Statistical Mechanics," John Wiley and Sons, Inc., New York, N. Y.; 1949.

[6] This principle is actually not essential to the derivation on account of the high dilution of the gas outside the metal, but is included for completeness since it has primary importance in discussions concerning the electrons inside a metal.

$$\Omega = \prod_j \frac{C_j!}{N_j!(C_j - N_j)!} \cdot \qquad (8)$$

Now the distribution (i.e. the set of N_j's) we are looking for is the one which will give the largest possible value of Ω, consistent of course with the conditions that

$$\sum_j N_j = N \quad \text{total number of particles} \qquad (9)$$

and

$$\sum_j \epsilon_j N_j = E \quad \text{total energy of gas,} \qquad (10)$$

where ϵ_j is the energy value of the region $(\Delta\epsilon)_j$.

Proceeding to maximize Ω, we transform (8) into a form which is more convenient to handle by taking the logarithm and by introducing Stirling's formula for the factorial.[7]

Using the method of undetermined multipliers, the maximum value of $\log \Omega$, consistent with (9) and (10) also being true, is given by solving for N_j the equation

$$\frac{d}{dN_j}\left[\log \Omega + \alpha \sum_j N_j + \beta \sum_j \epsilon_j N_j\right] = 0. \qquad (11)$$

The above operation is easily carried out and one obtains, for the equation from which the most probable set of N_j's may be computed

$$\frac{N_j}{C_j} = \frac{1}{e^{\alpha+\beta\epsilon_j} + 1}. \qquad (12)$$

This (with the constants α and β as yet undetermined) is the Fermi-Dirac formula for the probability that a given energy level will be occupied by an electron.

Before proceeding further with the calculation of the free energy of the gas, which is a thermodynamic concept, one must interpret the foregoing statistical concepts in thermodynamic terms.

(*c*) *Thermodynamic interpretation of the statistical quantities*. It is necessary to assign thermodynamic meanings to Ω, α, and β. For brevity, a proof of this matter will not be presented but it will be merely stated that a consistent scheme can be set up if one makes the following assignments

$$k \log \Omega = S \quad \text{entropy} \qquad (13)$$

$$NkT\alpha = \Psi \quad \text{free energy } (E - TS) \text{ of the system of } N \text{ particles} \qquad (14)$$

$$\beta = \frac{1}{kT} \cdot \qquad (15)$$

Verification of these relationships can be effected by setting up an equation for dS based on (13) and (8), and comparing the result with standard forms of the first and second laws of thermodynamics.

Once these analogies are established, (12) can be summed over all states and set equal to N, giving an equation in which the number of electrons per unit volume of gas is expressed as a function of the free energy.

At this stage of the derivation it is convenient to introduce an approximation which can be justified by examination in the light of end results. The demonstration of the thermodynamic correspondences and the developments which follow are greatly simplified by the fact that, for the cases considered, the quantity $e^{\alpha+\beta\epsilon_j}$ is very large compared to unity. As a result of these considerations the energy distribution in the gas at equilibrium can be written

$$\frac{N_j}{C_j} = e^{(\mu-\epsilon_j)/kT} \qquad (16)$$

where

$$\mu = \frac{\Psi}{N}, \quad \text{the free energy per particle.} \qquad (17)$$

(*d*) *Evaluation of the Summation*. To complete the energy distribution (16) the quantities C_j and E_j must be put into forms which will permit the summing over all energy regions.

Using (6), our quantum mechanical expressions for the energy of a gas particle in terms of integral quantum numbers, the desired equation can be written as follows

$$\sum_j C_j e^{(1/kT)(\mu - h^2K_j^2/8mV^{2/3})} = N \qquad (18)$$

in which we have put

$$K = K_x^2 + K_y^2 + K_z^2. \qquad (19)$$

The quantity K_j is the value of K associated with the jth energy region whose width in terms of K is now written as $(\Delta K)_j$. In order to evaluate the sum by a process of integration, the number C_j of levels included in each $(\Delta K)_j$ must be computed. Remembering the doubling of levels on account of spin, one sees that any set of three integral quantities K_x, K_y, and K_z corresponds to two levels. If one imagines these quantities plotted on rectangular axes, a given value of K will represent the radius of a sphere in the k space. Reflection will show that the number of sets of K_x, K_y, and K_z included in the energy region ΔK at K_j will be given by the volume of a spherical shell of radius K_j and thickness ΔK. Since only positive values of the K's are considered the volume to be used will be one eighth of the total shell. Thus we have,

$$C_j = (2)\tfrac{1}{8}4\pi K_j^2 \Delta K = (2)\frac{\pi}{2}K_j^2\Delta K. \qquad (20)$$

Substituting this in (18) and writing the sum as an integral we have

$$(2)\frac{\pi}{2}e^{\mu/kT}\int_0^\infty K^2 e^{-h^2K^2/8mkTV^{2/3}}dK \doteq N, \qquad (21)$$

---

[7] The approximate relation $n! = (n/e)^n$ is, for values of n encountered here, sufficiently accurate to be considered, for all practical purposes, exact.

whence we have after integration,

$$\nu = 2\left(\frac{2\pi mkT}{h^2}\right)^{3/2} e^{\phi'/kT} \tag{22}$$

where N/V has been replaced by ν, the number of electrons per unit volume of the gas, and μ has been replaced by ϕ', the free energy per particle in the metal, referred to a zero outside the metal. Since there is no net flow of electrons across the boundary in either direction, the free energies in the metal and in the gas, referred to the same zero, must be equal (i.e., $\mu=\phi'$). If one imagines the gas as having been removed, ϕ' is seen to be the negative of the work involved in removing an electron from the metal. The customary "work function" ϕ is seen to be equal to $-\phi'$.

Now introducing the kinetic theory relation between the number of particles per unit volume and the number hitting unit area of any surface per second,

$$n = \nu\left(\frac{kT}{2\pi m}\right)^{1/2} \tag{23}$$

and writing $I=ne$ where e is the electronic charge, we have from (22), the Richardson equation

$$I = \frac{4\pi me}{h^3}(kT)^2 e^{-\phi/kT}. \tag{24}$$

It should be realized that this equation has been derived with *no detailed knowledge of matters inside the solid.* All we have said about the inside of the solid is that the internal free energy per electron is equal to a number ϕ whose value remains to be assigned, either empirically or by additional theoretical developments.

The "whole story" of the material, both in regard to the work required to get an electron out, and also in regard to the density, and so forth, of the electrons inside, is included in ϕ, the so-called work function.

It should be noticed also that the derivation just completed *does not completely define the temperature variation of the emission.* For, as far as anything has been said, the free energy per electron (ϕ) might itself be strongly temperature dependent. For clean metals, however, it is a fact that emission data are reasonably well fitted by (24) with ϕ held constant. And theoretical arguments can be advanced to show that, in the case of metals, the temperature variation of ϕ is slight.

3. *Brief Sketch of the Inside Derivation*

In this treatment one assumes that the electrons in a material may be considered as a perfect gas in a volume V. Using some of the developments of the preceding section, in which the classical momenta P_x, P_y, and P_z are represented by the quantum numbers K_x, K_y, and K_z, one sees that the number of electrons having momenta in the range $dK_x\,dK_y\,dK_z$ may be written as

$$\frac{2dK_x dK_y dK_z}{e^{(\epsilon-\mu')/kT}+1}\cdot \tag{25}$$

In this expression, μ' is the free energy per electron within the solid referred to a zero inside, and it is only through μ' that any specific properties of the solid, such as density of electrons, appear. This expression is integrated from $K_x=K_x^0$ to $K_x=\infty$ where K_x^0 corresponds to that value of x momentum for which, if the y and z momenta were zero, the energy of the particle would equal $\mu+\phi$ where, as before, ϕ is the free energy referred to outside. Integrations with respect to K_y and K_z are taken from 0 to ∞ and the Richardson equation is obtained.

Consideration of the above will show that, even though the calculation is ostensibly "from inside" one has actually used no detailed knowledge of the interior. Just as in the outside derivation, one ends with all the properties of the solid expressed in ϕ, the free energy per particle referred to outside. It may be further remarked that, although the Fermi-Dirac distribution is used to write (25), the Fermi-Dirac form is never needed since $\epsilon-\mu$ is always sufficiently large that the 1 in the denominator can be ignored.

4. *Application to Metals: the Reflection Coefficient*

As stated above, the Richardson equation does not define the temperature variation of the emission unless further knowledge is available regarding the temperature dependence of ϕ. Also, from the foregoing considerations, it follows that if ϕ is independent of temperature, the value which one would find experimentally for A should be the theoretical value which is 120.4 amp/cm²deg².

In Table I, which lists values of A and ϕ for several metals, one sees that the experimental values of A show considerable variation from substance to substance although, except rhenium and nickel, they are of the right order of magnitude.

TABLE I*

Element	ϕ	A
Caesium	1.81	162
Barium	2.11	60
Zirconium	4.12	330
Hafnium	3.53	14.5
Thorium	3.38	70
Tantalum	4.1	60
Molybdenum	4.15	55
Tungsten	4.54	60–100
Rhenium	5.1	200
Nickel	5.03	1380
Palladium	4.99	60
Platinum	5.40	170

* R. H. Fowler, "Statistical Mechanics," The Macmillan Co., New York, N. Y.; 1936.

Of the substances listed, the greatest theoretical interest is attached to tantalum ($A=60$), molybdenum ($A=55$), and tungsten ($A=60$–100) because, owing to their high melting points, they are the metals which can be most effectively cleaned by flashing to high temperatures. It is to take account of this discrepancy between these values and $A=120$ that the reflection coefficient, along with certain other considerations relative to the temperature variation of ϕ, is introduced.

In the "outside" or equilibrium derivation, it is possible that not every electron which impinges upon the surface of the solid will enter. If the over-all fraction thus reflected is represented by r, the A factor must be multiplied by $1-r$.

In the "inside" derivation it is possible that not every electron which impinges upon the surface barrier from within will escape, even though its X-associated energy exceed ϕ. Again, if the average number thus reflected is r times the total number impinging, the A constant must be multiplied by $1-r$.

One might well ask whether the first r, referring to reflection from outside in the equilibrium derivation, should necessarily be the same quantity as the second r which pertains to an electron attempting to escape from inside. Remembering that the inside derivation is based upon a model of a number of free electrons in a box whose "walls" consist of a potential barrier, it appears reasonable that an electron of a given energy should have the same probability of reflection from within as from without, and a quantum-mechanical calculation shows that the two reflection coefficients are equal.

B. *Effects of Applied Electric Field*

As stated in Section I*A*, the usual procedures for measuring thermionic emission involve means for assuring that the electric field at the cathode surface is essentially zero. The Richardson equation which has been derived is not limited to the case of zero field, however. The work function ϕ is the free energy per particle, regardless of whether or not an accelerating field exists. The problem at hand is to compute the effect of the accelerating field on ϕ.

To do this one must go into the theory of the work function to some extent. Ideally, one would set up a mathematical model and then investigate how the presence of the electric field would affect the calculated value of ϕ. Actually, the complete calculation of ϕ is not feasible, but it turns out that, for the magnitude of electric field encountered in practice, a partial theory of ϕ suffices.

In formulating this problem it is convenient to choose the zero inside the material instead of outside. Referring to Fig. 3, we take the zero at an energy difference ϕ below the field-free value outside. We then consider ϕ divided into two parts:

ϕ_a = the energy of an electron at $x=a$ referred to the zero inside

and

ϕ_i = the energy difference between $x=a$ and $x=\infty$.

The distance $x=a$ is chosen sufficiently far from the surface that all short range forces are negligibly small. Thus the energy ϕ_i can be attributed entirely to the *image force attraction* between the electron and the metal.

In other words, one has split up ϕ into a very complicated part ϕ_a which is due to several kinds of difficult-to-evaluate forces, and a simple part ϕ_i which is entirely due to image force. Happily, it turns out that the application of electric field of practical magnitude alters ϕ_i in an easily calculable manner, and has negligible effect upon ϕ_a.

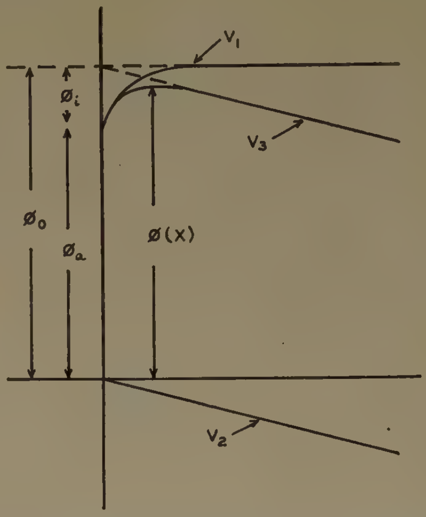

Fig. 3—Diagram illustrating Schottky effect. The field-free work function ϕ_0 is reduced to the field-dependent work function $\phi(X)$.

Referring to Fig. 3, V_1 represents the energy of the particle as a function of x, in the absence of the field. V_2, the straight line, gives the energy component due to the field X. V_3 is the resultant and has a maximum whose height ϕ(X) is the field-dependent work function, the quantity we are seeking.

With the above as preliminary, the calculation of ϕ(X) is straightforward. From electrostatics, the attractive force on an electron in the region $x>a$ is $e^2/4x^2$ whence, in the same region,

$$V_1 = \phi_0 - \int_x^\infty \frac{e^2}{4x^2}\,dx \tag{26}$$

where ϕ_0 is the field-free value of ϕ.

This becomes on integrating

$$V_1 = \phi_0 - \frac{e^2}{4x}. \tag{27}$$

Now V_2, the potential component due to the applied field is simply $-eXx$, hence we have for the resultant,

$$V_3 = \phi_0 - \frac{e^2}{4x} - eXx. \tag{28}$$

Finding the maximum value of V_3 in the usual manner, one has

$$\phi(X) = \phi_0 - \sqrt{X}\, e^{3/2}. \tag{29}$$

Substituting this expression for ϕ(X) into the Richardson (24), one obtains

$$I = AT^2 e^{\phi_0/kT} \cdot e^{e^{3/2}\sqrt{X}/kT}, \tag{30}$$

or, representing $AT^2e^{-\phi_0/kT}$ by I_0, the field-free emission, one has the Schottky equation in a customary form:

$$\frac{I}{I_0} = e^{e^{3/2}\sqrt{X}/kT}. \qquad (31)$$

When measurements are made of the thermionic emission from clean metals in the presence of accurately known electric fields it is found that (31) is quite well obeyed, and experiments of this type have yielded satisfactory values of the electronic charge e.

It should be mentioned here, however, that this phenomenon is one in which the wave nature of the electrons plays a distinctive part and a quantum mechanical calculation of the effect yields a more complicated expression which differs from (31) to an extent which can be experimentally verified.

Measurements of field effects on complex surfaces, such as semiconductor emitters, tend to follow the $\sqrt{X}$ dependence with fair accuracy but, when log I/I_0 is plotted against $\sqrt{X}$, the slopes will yield incorrect values of temperature. In general, the variation with $\sqrt{X}$ will be more rapid than the equation predicts. Several factors may be invoked to account for this discrepancy, one of the most discussed being the "patch theory." If a surface is a mosaic of patches of different values of ϕ local fields will be present, which are attractive for the patches of low ϕ. When an external field is applied the resultant effect of the applied and local fields is such as to account for the phenomena in a semiquantitative manner. Also with a semiconductor the image force expression may itself be more complex, may involve the dielectric constant, etc.

C. Electron Emission from Semiconductors

1. General Remarks Concerning Metals and Semiconductors

From Section II*A* it is evident that derivation of the Richardson equation requires no detailed knowledge of the nature of the material. It is only necessary to specify that the removal of n electrons from the solid will change the free energy of the solid by an amount $n\phi$. This statement, and the derived form of the Richardson equation, are as applicable to semiconductors as to metals. The difference lies in the temperature dependence of ϕ.

Empirically, as the name indicates, a semiconductor differs from a metal principally in having a much smaller value of electrical conductivity. A further difference lies in the fact that the conductance of a semiconductor increases as the temperature increases while that of a metal is comparatively constant and indeed decreases. These properties of semiconductors are explained by a theoretical picture in which the "band structure" plays an important part. This matter, which may be mathematically justified on quantum mechanical grounds, will now be qualitatively described.

As stated earlier, many properties of a metal can be explained by the model in which a number of electrons are confined, in the manner of a gas, to a certain volume. The electrons concerned may have any value of energy from zero upwards.[8] With semiconductors this is not the case.

Quantum mechanical considerations, dealing with the nature of electrons in crystals, require that "gaps" exist in the energy scale. No electrons may have energy values within a gap. Thus, instead of having the closely spaced energy levels distributed throughout the whole range we find them confined to specific regions known as "bands." The theory tells us further that a band in which all levels are occupied by electrons cannot contribute to conduction. Only a partially filled band can so contribute. In the case of metals, referred to above, one is speaking of the uppermost band, which, for metals, is only partially filled by a number of electrons which does not vary with temperature. For semiconductors the population of the uppermost band varies with temperature and the band is empty at zero temperature.

In the simplest model of a semiconductor one has, as shown in Fig. 4, two bands of allowed energy. The lower one is called the "filled band" and has all possible energy states occupied by electrons. The upper band is sufficiently high in the energy scale so that, at zero temperature, none of its levels are occupied. Thus at zero temperature no electrons are present which can take part in conduction and the semiconductor is an insulator.

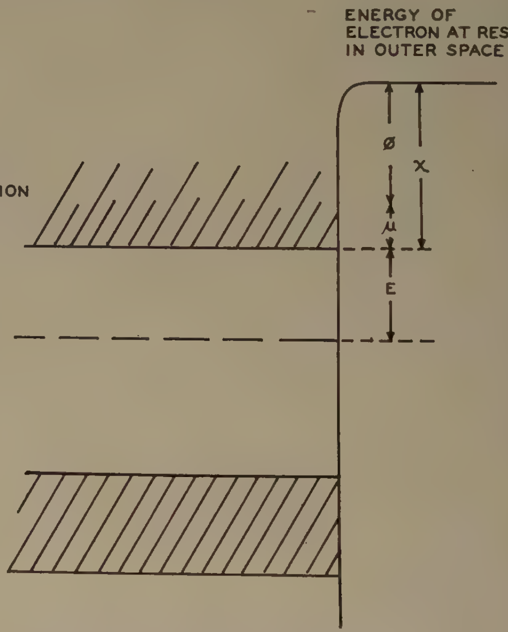
ENERGY OF ELECTRON AT REST IN OUTER SPACE
ø
χ
μ
E
CONDUCTION BAND
IMPURITY OR DONOR CENTERS
FILLED BAND

Fig. 4—Simplest model for conductivity and thermionic emission of semiconductor.

At higher temperatures, however, the thermal energy results in some electrons being excited to levels in the unfilled band and some conductivity appears. Because of this circumstance, the unfilled band is commonly referred to in the literature as the "conduction band." The electrons in the conduction band are those which take part in thermionic emission.

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[8] Strictly speaking, this is not a continuum but consists of a very large number of closely spaced levels as defined by (6).

In reality, it appears, however, that in most cases so far studied the filled band is so far below the conduction band that practically no electrons are excited to the conduction band by ordinary operating temperatures. The fact that a semiconductor conducts as much as it does is due to the presence of "impurities" which disturb the level diagram of the pure substance and may cause the presence of allowed levels at some point not too far below the conduction band. Centers capable of supplying electrons, whether resulting from impurities or other circumstances, are commonly referred to as donors.

The so-called impurities may be substances foreign to the semiconductor, or, if the semiconductor is a compound, the additional substance may be an excess of either elementary component of the compound.

The process by which the impurity is added is called "activation." This process applies not only to conduction as explained above but, since it is the electrons in the conduction band which take part in thermionic emission, the same type of activation is required to make a semiconductor emit.[9]

2. Plan of the Calculation

As stated above the Richardson equation (24) applies to any class of substance. The fact that ϕ, in general, varies with T, means that the equation is of little use in the form of (24) unless further knowledge of $\phi(T)$ is available.

In metals, it can be shown that ϕ, the free energy per electron, changes very little with temperature. Thus when ϕ is assumed constant, the equation fits the emission data reasonably well and the experimental value of A agrees approximately with the theoretical value.

With semiconductors the distribution of the electrons among the bands varies strongly with temperature, and therefore the free energy ϕ will also show marked variation. This theoretical circumstance is reflected in the fact that, although semiconductors also show reasonable agreement with (24) with a constant ϕ, the value of A may be wrong by many orders of magnitude.

Our plan, therefore, is to carry out a line of theoretical argument which will give $\phi(T)$ for the simplest impurity semiconductor model and to substitute the expression for $\phi(T)$ in the general Richardson equation (24).

In doing this, it is pictured that only the electrons in the conduction band are taking part in the thermionic emission. The first subject of computation is therefore the number of electrons in the conduction band. These are then considered as an ideal gas confined to a given volume and the free energy is computed, referred to the bottom of the conduction band as zero. Letting this quantity be $\mu(T)$, and letting χ be the energy of the bottom of the conduction band referred to a zero outside the crystal, it is seen that the desired $\phi(T)$ is equal to $\chi-\mu(T)$.

The presence of impurities in the lattice can give rise to conduction, and affect the thermionic emission, by other specific processes than that which is here chosen. For example, the presence of vacant impurity centers whose energy is only slightly above the filled band may cause conduction by relieving that band of a few of its electrons. For the calculation of ϕ all such possibilities must be taken into account. In the present paper we restrict ourselves to one particular picture.

3. Number of Electrons in the Conduction Band

Referring to Fig. 4 we assume the existence of N impurity centers, each of which is capable of supplying one electron to the conduction band. We then make a provisional assumption that n of these N available electrons are in the conduction band, and we calculate the thermodynamic potential[10]

$$F = U - TS + pV, \tag{32}$$

which will be a function of n. The value of n corresponding to equilibrium will then be that value for which

$$\left(\frac{\partial F}{\partial n}\right)_T = 0.^{11} \tag{33}$$

The quantity U in the above expression is the total energy of the system.

To compute the TS term, we again use the relation $S=k \log \Omega$ (13) where Ω is the number of possible arrangements of the electrons. We then write

$$\Omega = \Omega'\Omega'' \tag{34}$$

where

Ω' = number of arrangements of the n electrons in the conduction band

Ω'' = number of ways in which these n electrons can be taken from the N impurity centers.

To compute Ω' we write[12]

$$\log \Omega' = \frac{U}{kT} - \frac{n\mu}{kT}, \tag{35}$$

---

[9] This statement may be found, in the future, to have certain exceptions, Although it is true without question in the case of alkaline earth oxides and of thorium oxide at low temperatures, it remains a possibility that thorium oxide at the highest operating temperature may not require the presence of impurities.

[10] Choice of the thermodynamic potential in this form leads to the customary expression for the number in the conduction band. Using the form $\Psi=U-TS$ introduces a factor of $e^{1/2}$ in the same expression.

[11] The reader may wish to compare the derivation which follows for the density of electrons in the conduction band with that outlined by N. F. Mott and R. W. Gurney, "Electronic Processes in Ionic Crystals," Clarendon Press, Oxford, England, pp. 156–160; 1941.

[12] This expression may be understood by considering that $k \log \Omega'$ is the entropy of the electrons in the conduction band whence, from the definition of free energy, $n\mu=u-kT \log \Omega'$.

where, as before, U is the total energy of the system. The quantity μ may now be evaluated in a manner analogous to (18)–(22), except that the summation is equated to n and the expression for the energy must contain the width E of the forbidden region. (The origin of energy is taken at the impurity levels.) In line with this, we write, analogous to (21)

$$\frac{\pi}{2} e^{(\mu-E)/kT} \int_0^\infty K^2 e^{-h^2K^2/8mkTV^{2/3}} dK = n \tag{36}$$

whence

$$-\frac{\mu}{kT} = \log 2\left(\frac{2\pi mkT}{h^2}\right)^{3/2} \frac{V}{n} - \frac{E}{kT} \tag{37}$$

which, with (35), completes the computation of Ω'.

The computation of Ω'' is relatively simple, involving as it does only the formula for the number of combinations of N things taken n at a time. Thus we have

$$\Omega'' = \frac{N!}{n!(N-n)!}, \tag{38}$$

whence it may be shown, using Stirling's formula, that

$$\log \Omega'' = N \log N - n \log n - (N-n) \log (N-n) \tag{39}$$

and

$$\frac{\partial}{\partial n} \log \Omega'' = \log\left(\frac{N-n}{n}\right). \tag{40}$$

To proceed with the formulation of (32) we may now write, observing that $pv = nkt$,

$$F = nkT \log 2\left(\frac{2\pi mkT}{h^2}\right)^{3/2} \frac{V}{n} - nE$$
$$+ nkT + kT \log \Omega''. \tag{41}$$

Differentiating this with respect to n and equating to zero, we have

$$\frac{n^2}{N-n} = V \cdot 2\left(\frac{2\pi mkT}{h^2}\right)^{3/2} e^{\cdot E/kT}. \tag{42}$$

It may now be assumed that for practical cases $n \ll N$, so that (42) may be written

$$\nu = 2n_0{}^{1/2}\left(\frac{2\pi mkT}{h^2}\right)^{3/4} e^{-E/2kT}, \tag{43}$$

where ν is the number of electrons, per unit volume, in the conduction band, and n_0 is the number of impurity centers per unit volume.

As suggested earlier, the particular expression which one obtains for the number in the conduction band and for the quantity ϕ, will depend upon the particular model which one chooses as most nearly representing the state of affairs within the material. The above assumption that the number of available electrons is the same as the number of centers in which they may be located is somewhat arbitrary and is subject to verification for the material at hand. Another one of many possible situations might be that a number of the centers are vacant even at zero temperature. In this case the number of impurity centers (N) and the number of electrons (N_e, say) are different. Then, instead of (38), one has

$$\Omega'' = \frac{N!}{(n+N-N_e)!(N_e-n)!}, \tag{44}$$

whence one obtains, instead of (43), and again assuming $n \ll N_e$

$$\nu = \frac{N_e}{N - N_e}\left(\frac{2\pi mkT}{h^2}\right)^{3/2} e^{-E/kT}. \tag{45}$$

4. *The Emission Formula*

We refer again to Fig. 5 which is the diagram pertinent to electron emission from the simplest model of semiconductor.

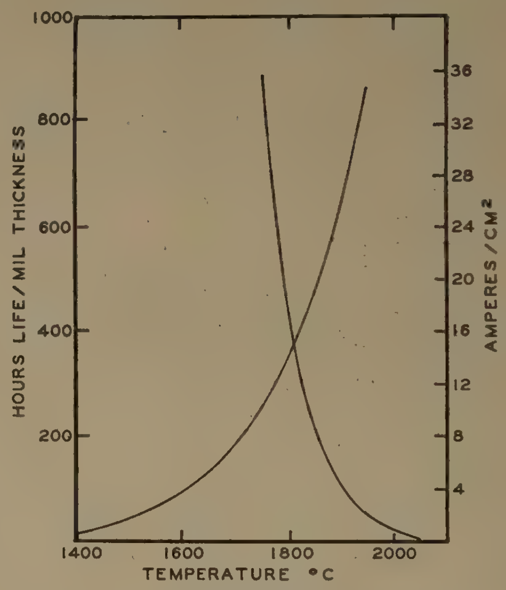

Fig. 5—Rate of evaporation and thermionic emission of thorium oxide, both as function of temperature.

As before, the work function, or ϕ in the Richardson equation (24), is conceived as the free energy per electron referred to a zero outside. This is seen in the diagram to be the resultant of χ, the energy of the bottom of the conduction band referred to outside and μ, the free energy of an electron in the conduction band referred to the bottom of the band. Positive values of μ are drawn upwards; actually μ will be negative, as shown.

One then writes

$$\phi = \chi - \mu \tag{46}$$

and the Richardson equation is accordingly written in the form

$$AT^2 e^{-\chi/kT} \cdot e^{\mu/kT}. \tag{47}$$

The evaluation of the factor $e^{(\mu/kT)}$ involves the sum over all states of the electron gas in the conduction band and can proceed in the same manner as that by which (22) was derived. Starting with (18), but equating the sum to n, we obtain

$$e^{\mu/kT} = \frac{\nu}{2}\left(\frac{h^2}{2\pi mkT}\right)^{3/2} \tag{48}$$

where ν is the number of electrons per unit volume in the conduction band. Putting (48) in (47) and using (43) for ν, the Fowler equation for the thermionic emission from the simplest semiconductor is obtained

$$I = AT^2 n_0^{1/2}\left(\frac{h^2}{2\pi mkT}\right)^{3/4} e^{-(\chi+E/2)/kT}. \tag{49}$$

It seems worth repeating that this is not a different equation from the usual Richardson equation (24). It is the same equation with the ϕ replaced by a particular temperature-dependent form. The following points are of interest. Writing the equation in the following form in which it might be immediately compared with a specific set of data,

$$I = aT^{5/4}e^{-b/kT} \tag{50}$$

one observes that:

(a) The quantity b is independent of temperature.

(b) The temperature no longer appears in the coefficient as T^2, but as T.$^{5/4}$

(c) The a is no longer a combination of universal constants, but now involves a constant of the material, namely, the density of impurity centers.

When one makes the usual "Richardson Plot" $\log I/T^2$ versus $\frac{1}{T}$ for semiconductors, one obtains a reasonably good straight line and is tempted to conclude that this indicates a "work function" independent of temperature. The above considerations show that this is only justified if the theoretical A is obtained. With semiconductors the value of the constant slope corresponds to a combination of energy level values of the material but does not mean a constant "work function."

III. SOME APPLICATIONS OF THE FORMULAS

A. The BaSr Oxide Emitter

1. General Remarks

By far the most commonly used semiconductor emitter is a mixture of barium oxide and strontium oxide in the form of a thin coating on a metal base. Since these oxides react with the atmosphere, such a cathode is usually made by applying the materials in the form of the carbonates, and subsequently decomposing the carbonates in the vacuum by heating.

As is well known, such a system, with proper preliminary treatment known as "activation," will at red heat yield values of emission for which a pure metal such as tungsten would require white heat and therefore many times as much heating power.

Although the BaSr oxide emitter has found widespread practical application for many decades, the actual value of emission of which a given cathode is capable at a given temperature is a highly variable matter. On the simplest theoretical picture, the emission is proportional to the square root of the number of impurity centers (n_0) and the latter quantity is by no means well defined. It is (in this picture) the function of the activation process to produce the impurity centers. This is thought at present to be the liberation of free barium or strontium atoms in the lattice and the number of centers produced can vary over wide limits depending upon (a) the constitution of the coating, (b) the nature of the base metal, (c) the precise schedule of heat treatment and current drawing, and (d) various "poisoning" or deactivating circumstances which may be present such as gas liberated from the anode, imperfect vacuum, and the like.

In addition to variations of the number of impurity centers, other circumstances may cause the emission to vary, still referring to the simplest picture. At least as important as variations of n_0 are variations of χ, the electron affinity, i.e., the difference of potential energy between the bottom of the conduction band and a point just outside the crystal.

If, for example, a layer of atoms is deposited on the surface in such a manner that negative charges tend to be inward and positive charges outward, an electron will gain energy as it passes outwards. The effect of such a double layer of charge will be to reduce χ and increase the emission. Such surface conditions may vary with considerable rapidity and may be constantly changing during the life of a tube.

Thus, unlike a metal whose emission, under good vacuum conditions, is a rather definite quantity, the emission of an "oxide cathode" is not well defined. In the majority of practical applications this is not serious, however, because, the material being such a good emitter, there is always more emission than is being demanded. In other words the majority of electron tubes operate in the space-charge-limited state in which, as in a receiving tube, the cathode might be ready to yield emission of the order of 1 ampere while only a few milliamperes are demanded. Under such conditions wide variations of the cathode's emitting power may be taking place with the user being completely ignorant of them.

In regard to the theory of emission, these vagaries of the oxide cathode have of course retarded development of precise theoretical explanations.

2. "Pulsed" Emission and Decay

Previous to World War II all cathodes were generally evaluated under dc or sinusoidal ac conditions. A good oxide cathode might provide as much as 1 amp/cm^2 at 1,100°K, although the design figures for high-vacuum operation were generally less.

During the war, however, there appeared the pulsed magnetron in which emission was called for in pulses of very short duration, of the order of one microsecond. To their own surprise, as well as that of everyone else, tube engineers began speaking in terms of 10, 20, and 50 amp/cm². Under laboratory conditions, emissions as high as 150 amp/cm², space-charge limited, were observed.

Thus it was discovered that the emitting power of the BaSr oxide system varied more rapidly with time than had been previously supposed. After application of anode voltage, the emission would fall very rapidly with time according to a function which, when approximately represented by a sum of exponentials

$$I = I_0 + I_1e^{-t/\tau_1} + I_2e^{-t/\tau_2} \tag{51}$$

would have a large component with a time constant (τ) as small as 10^{-5} seconds. Furthermore, the amounts of the various decay components (i.e., the relative values of I_0, I_1, and I_2) will themselves vary with time in a complicated manner.

To account for these decay effects on the basis of the simplest picture, we again consider possible variations of n_0 and χ. One seeks possible mechanisms whereby n_0 and/or χ, and therefore the electron emission, are altered by the passage of electron current.

According to the most widely held view at the moment, the impurity centers are free barium atoms and are generated either by the reducing action of the base metal or by electrolysis by the passage of current. Dissociation of the material by the high temperature alone is found to be improbable on the basis of energy considerations. Diminution of the barium concentration will occur by evaporation and by diffusion in the electric field. The concentration n_0 which exists at a given time will be the result of a complex dynamic equilibrium among the above factors, probably also involving others which have not been mentioned.

Several aspects of ionic conduction, loosely included above in the word electrolysis, have a bearing on cathode behavior. As everyone knows who has activated oxide cathodes, a coating which initially has reached its apparent upper limit[a] of emission as produced by thermal treatment alone, will always attain a higher state of activation when a large current is drawn. This is thought of as the liberation of barium at the base metal and subsequent diffusion of neutral atoms back into the coating. During this process oxygen should pass to the surface and escape and such evolution of oxygen from a cathode being activated may be observed. In this aspect, the ionic conduction assists in the initial activation of a cathode and passage of current, instead of causing decay, actually increases the emitting power of a cathode. Oscillograms taken with a fresh unseasoned cathode will often show examples of "negative decay," presumably from this cause.

In sofar, however, as the barium exists in the material as ions, rather than as neutral atoms, one might expect transient reduction of n_0 by the sweeping out of ions by the electric field which accompanies the passage of current of high density.

An approximate calculation shows that such effects might occur with sufficient rapidity to account even for decay occurring in microseconds. Measurements on well activated coatings of about 3×10^{-3} cm thickness show resistances across unit area of the order of magnitude of 1 ohm-cm², or specific resistances of about 300 ohm-cm. Thus a current of 10 amp/cm² will give rise to a field of 3,000 volts/cm in the coating. Values of mobilities of the barium ions are not known, but investigations of other materials suggest a value of the order of 1 cm/sec per volt/cm. Thus the velocity of an ion might be 3,000 cm/sec which, in a time of 1 microsecond, would result in a displacement of 3×10^{-3} cm, which happens fortuitously to be the assumed thickness of the entire coating. Thus a significant fraction of ionic impurity centers might be swept out of a coating in times of the order of microseconds. However, whether the impurity centers may indeed be considered as ionic is made subject to serious doubt by consideration of the low value of ionic conductivity of the coating.

Explanation of decay on the basis of changes of χ are easy to suggest qualitatively although, quantitatively, the picture is still incomplete. Anything which alters the character and population of the surface layer of atoms and the layers immediately behind it is a candidate. Among these, one has surface changes originating from inside, such as diffusion of barium away from the surface and of oxygen onto the surface, and those caused from outside as, for example, material from the anode, liberated by the electron bombardment, ionized and carried forcibly to the cathode surface. Since the transit time of ions may be of the order of 10^{-7} seconds, one sees that even the latter process may occur with sufficient rapidity to contribute to microsecond decay.

B. *Application of the Emission Equation*

We turn now to a discussion of equation (49) in (relation to "oxide" cathodes. As implied above, the complete picture of this emitting system has not been attained and we shall not, in this paper, enter into the details of the most recent attempts.

One of the most valuable of experiments in establishing the truth of the barium-impurity theory are measurements by chemical means of the amount of free barium in an activated cathode coating. This is accomplished by exposing the activated coating to water vapor and measuring the amount of hydrogen generated by reaction with the free barium. Values of the order of 10^{18} barium atoms per cm³ are obtained with 3×10^{18} a probable figure for highly activated coatings.

In regard to the quantity $\chi+E/2$, one may find values between 1 and 2 electron volts and may consider 1.2 as a probable value for pulsed (i.e., "undecayed") emission.

Using the above values in (49) one finds $I=27$ amp/cm³ at 1,100°K, a reasonable value for a moderately good oxide cathode.

In regard to values of χ and E, conductivity studies[13] yield values of E in the neighborhood of 0.7 e volts which requires a χ of about 0.85 e volts to be consistent with the above value of $\chi+E/2$.

C. The Thorium Oxide Emitter

1. General Remarks

While not competing with BaSr oxide in ability to yield high emission at low temperature, the thorium oxide cathode is useful in certain high-power applications where greater ruggedness is required. This ruggedness has two aspects: (1) the material is more refractory; it offers greater resistance to arcing and sparking; in the case of magnetrons it will absorb more back-bombardment without damage; and (2) greater stability of activation results in the following advantages: (a) the initial processing is less critical; (b) the cathode is relatively immune to poisoning; (c) it is operable in poor vacuum; (d) the emission decays more slowly, permitting longer pulses; and (e) larger values of stable dc are available.

Although the much greater heater power required by thoria is a serious disadvantage for applications such as receiver tubes, it is less objectionable in the power field. In fact, as regards magnetron application, the requirement to dissipate back-bombardment makes it advantageous to operate cathodes at higher temperatures than BaSr oxide will permit.

The high values of dc emission, 2–3 amps/cm^2, which are readily available with fresh cathodes have not always given the life which would be desired. Considerable disparity exists among results to date and efforts are being made to appraise the relative importance of electrolysis and ion bombardment in the erosion effects observed when thoria emitters are used for high dc and in very high duty cycle applications.

2. Relation of Emission to Evaporation

The usefulness of any substance as an emitter is obviously related to its vapor pressure-versus-temperature characteristic. It is necessary that, at the temperature which is required for the desired electron emission, the rate of evaporation of the material be not excessive. The reason tungsten is a better thermionic emitter than, say, copper, is not that it has a lower work function (for indeed its work function is higher). It is a better emitter because it can be heated, without excessive evaporation, to those temperatures where superior emission is available.

Considering emitting materials in general, a large number, indeed a majority, must be rejected on these grounds, namely, that as the temperature is raised, objectionable evaporation appears before the desired emission is available.

Among the refractory compounds, thorium oxide has a relatively good relationship between emission and evaporation although, in some applications, the evaporation will be a limiting factor. In Fig. 5 the thermionic emission, and the life per mil thickness due to evaporation, are plotted on the same diagram, both as a function of temperature. One sees that, at approximately 1,800° C, the thermionic emission has become 14 amps/cm^2 while the material is evaporating at such a rate that one mil thickness disappears in about 350 hours.

3. Stability of Activation

The relative stability of activation which renders thorium oxide less sensitive to various poisoning influences is not understood. On the simple picture one would look for reasons why the "impurity centers" of thorium oxide have less affinity than those of barium oxide for the particles of any substance which could render them ineffective. Specifically, if, as seems probable, the impurity or donor centers are thorium in the former case, and barium in the latter, oxygen would be a potent deactivator in both cases. Why, other things being held constant, the rate of elimination of barium donors by a given oxygen concentration should be more rapid than that of thorium donors has not been established. As regards deactivation through increase of χ, one again sees no reason why barium-oxide should be more susceptible than thorium oxide. Again one would have to assume different affinity for surface films, and/or different effectiveness of such films as regards altering χ. One plausible speculation in this connection involves the fact that thorium oxide, since it operates at the higher temperature of 1,600° C, probably carries a less dense and less complex surface film than does BaSr oxide at 800° C. This is born out by observations that the emission from thoria at lower temperatures (1,200°, say) is more susceptible to poisoning than is the 1,600° emission.

Like BaSr oxide, a thorium oxide cathode will show current decay which recovers during an off period. But the rate is much less with the latter compound, the shortest time constants being of the order of tenths of seconds instead of 10^{-5} seconds as observed with BaSr oxide.

4. Application of the Semiconductor Equations

As with BaSr oxide, the simple semiconductor theory shows some success as a first approximation. Taking the experimental values $\chi+(E/2)=2.5$ e volts, and $I=14$ amps/cm^2 at 2,073°K one computes, using (49), a value of 2×10^{17} for the density of donor centers.

As yet no direct chemical measurement of n_0, based on the free thorium hypothesis, has been made. Studies of the electrical conductivity as a function of temperature yield values for n_0 of the order of 10^{17} or 10^{18} but further work is required before quantitative verification can be said to be achieved.

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[13] Writing the conductivity σ as $\sigma=\nu e v$ where ν is the density of electrons in the conduction band, e the electronic charge, and v the mobility, the temperature dependence of the conductivity will be the same function as ν, (43) or (45), etc. The quantity E is obtained from the slope of the straight line obtained by plotting $\log\sigma$ versus $1/T$.

During activation, the value of $E/2$ as determined from conductivity falls from approximately 3 volts to about 0.5 volt. In thermionic emission experiments values of $\chi+(E/2)$, over a range of activation estimated as similar, have been found to be 4.5 volts to 2.5 volts, suggesting a value of χ in the range of 1.5 to 2.0 volts.

D. Other Semiconductor Emitters

In addition to thorium oxide, numerous other materials have been investigated in the attempt to find a cathode material which will be more rugged that BaSr oxide and, at the same time, require less heater power than tungsten or tantalum.

The emission from several such materials is shown in Fig. 6 plotted against temperature. Curves for thorium oxide and for tungsten are included for comparison. To appraise the usefulness of any of these emitters at the present time would be premature. It would be surprising, however, if interesting developments did not arise among this group of materials in the near future.

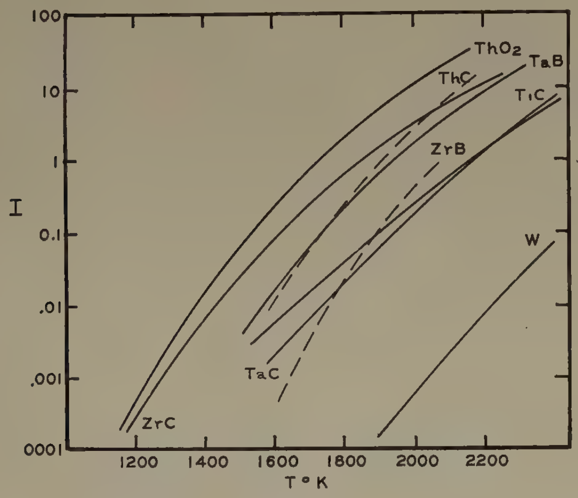

Fig. 6—Thermionic emission of several refractory compounds as function of temperature. A curve for tungsten is included for comparison.

IV. ELECTRON EMISSION FROM THIN FILMS ON METALS

A. General

In the case of emission from a metal one visualizes an ideal gas of electrons confined within a potential barrier whose height is a characteristic of the pure metal.

In the semiconductor picture, the same electron gas model is visualized, where, however, the concentration of electrons is not constant but varies with temperature.

In both cases one has a potential barrier which has, ideally, a definite value for the pure substance, but which is subject to alteration by adsorption of a layer of foreign material. We refer in this section to two instances in which the reduction of barrier height by a layer of foreign material is the basis of emitters of practical importance.

B. The Thoriated Tungsten Emitter

From the viewpoint of practical importance, the thoriated tungsten emitter should be near the beginning of this paper rather than near the end. Consisting of tungsten on which is formed a layer of metallic thorium, one atom thick more or less, it yields good emission at temperatures considerably lower than those required for pure tungsten. Emission values are similar to those with thorium oxide. Its advantage over barium oxide is mainly due to greater freedom from arcing and sparking in high voltage applications.

When tungsten which contains one or two per cent of thorium oxide is flashed at a very high temperature, (2,500° C), some of the oxide is reduced. If the material is then held in the neighborhood of 1,800° C for an approximate length of time, metallic thorium diffuses out of the bulk material and forms a monomolecular layer on the surface. This has the effect of reducing the potential barrier at the surface and therefore the value of ϕ, the free energy per electron. To minimize evaporation of the thorium layer, operation of the cathode is at a temperature below that used to form the layer.

If the general Richardson equation (24) is used for thoriated tungsten, and log I/T^2 is plotted against I/T in the customary manner, a reasonably good straight line is obtained but the value of A is much less than the theoretical, being approximately 3 instead of 120. One has, therefore, either to postulate a reflection coefficient of 97.5 per cent, or take what seems a more probable alternative and assume that the reduction of the work function by the thorium layer is itself a function of temperature. If, for example, one postulates that the work function of tungsten ϕ_W is reduced by an amount which decreases linearly with temperature, i.e., if one writes (24) in the form

$$I = AT^2 e^{-[\phi_W-(\phi_0-\alpha T)]kT} \tag{52}$$

one will have

$$I = Ae^{-\alpha/K}T^2 e^{-(\phi_W-\phi_0)/kT} \tag{53}$$

in which α may be assigned to give the observed value of $Ae^{-\alpha/K}$. It seems plausible that, as the temperature is raised, the ϕ should tend to approach the higher value characteristic of pure tungsten.

Values of the constant exponent $\phi_W-\phi_0$ are very nearly the same as values of $\chi+E/2$ found for bulk thoria and the magnitude of emission is similar.

One weakness of thoriated tungsten which has limited its use arises from its thin-film nature. Its emission depends upon the maintenance of the film and therefore is subject to rapid deterioration by positive ion bombardment. Treatment of the material in carbonaceous vapors, presumably converting the film to thorium carbide, increases markedly the resistance to ion bomardment. It also increases the temperature at which the cathode may be operated without too rapid evaporation of the film, and hence augments the available electron emission.

C. The Porous Tungsten-Barium Oxide Emitter

Very recently a successful emitter has been developed in which the emitting body is porous tungsten, prepared by powder-metallurgy methods, through which barium oxide is permitted to diffuse from inside. The emitting surface is thought to be mainly metallic barium on tungsten. The body is operated at temperatures up to 1,200° C at which very large emission values are reported.

Technically speaking, it seems probable that this type of development opens an important field of application where very high emission densities are required. It is too early, at present, to give a final appraisal of the evaporation problems which may be associated with this emitter. The matter is undergoing study in several laboratories.

Reliability in Miniature and Subminiature Tubes*

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Summary—**The meaning of the term "reliability" as applied to electron tubes is discussed, and the thesis is developed that reliability is a function not only of tube design and quality but also of the relationship between tube ratings and the operating conditions and requirements. Specific features of the miniature and subminiature tubes are discussed with respect to factors affecting tube reliability, such as mechanical ruggedness, operating temperature, emission stability, and life. General comments are made on the over-all effect of reduction in tube size on life and reliability.**

THE MEANING OF TUBE RELIABILITY

IT IS APPROPRIATE in any discussion of tube reliability to consider what the term reliability should be expected to cover. It would seem to be axiomatic that the term has significance only with reference to some specified or implied standard of performance and of operating conditions. This is a point that seems to have been very much underemphasized in recent discussions of the subject.

The electric motor has been cited as a device having the reliability that is needed in radio tubes. It should be pointed out that an individual motor is reliable only when operated under the service conditions for which it was designed and rated. Now, a radio tube is a much more complicated device than a motor and is inherently more vulnerable to failure from a variety of causes. However, reliability of the same order is a worthwhile goal for tube designers and manufacturers to work toward and it is one they can come close to reaching, provided operating conditions and performance requirements are properly related to the tube ratings. A number of instances can be cited of tube applications where tube reliability of this order has been regularly experienced.

In the great majority of military and commercial applications there is a surprising dearth of reliable specific information as to the tube defects causing equipment failure. In one class of application, commercial airlines, some fairly dependable figures obtained recently indicate that out of the one per cent of tubes that failed prematurely in service, three quarters developed mechanical faults, shorts, opens, glass faults, and one quarter were found to have electrical faults. These were specially designed and controlled tubes made in regular production and they were operated under conditions that were normal for aviation service, that is, with wide variations in supply voltages and moderately severe shock and vibration.

Mechanical defects are tangible and amenable to fairly definite corrective measures. Failure due to these defects can be reduced to a vanishingly small figure at the expense of systematically improved techniques and controls in manufacture. In other words, a high degree of mechanical reliability is definitely achievable.

Reliability in electrical characteristics and performance is a more elusive problem. Basic and practical research gives promise of pointing the way to improved materials and improved controls in materials and processing techniques. At the same time, a high degree of reliability in electrical performance has been obtained in many applications with existing tube types under favorable operating conditions.

This brings up the whole question of the relation between operating conditions and tube ratings. In any mechanical structure where reliability is required, it is the universal practice of the designer to introduce a considerable factor of safety in accordance with accepted standards for the material and the application. In the electrical aspects of electronic equipment this factor of safety frequently seems to be reduced very close to unity, or sometimes to less. It has been suggested that

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this condition results from the tendency for the radio equipment designer to revert to his original amateur habits when he deals with radio tubes. Actually, there are other more reasonable causes for this situation.

One is the inherently low power efficiency of thermionic tubes in terms of the ratio of output to total input including cathode heating power plus *B* power. Coupled with this is the relatively high cost of the power supply in terms of space and weight. This is particularly the case in many military applications.

Another factor is the frequent practice of making the equipment performance dependent on some very critical tube characteristic or one that has not been, or perhaps can not be, adequately controlled in tube manufacture.

Now these nonconservative practices have frequently resulted from the ingenuity of the equipment design engineer in devising new tube functions and attributes and operating conditions, and they have had a very healthy influence in expanding the tube ratings and fields of usefulness. However, during the period that these new operating conditions are in the experimental or pioneering stage they involve an appreciable degree of *un*reliability. They do not become appropriate for equipment with severe reliability requirements until the tube manufacturing techniques and controls have been developed to the point that the tubes can be conservatively rated for these particular conditions and characteristics.

These comments might be summarized by saying that so far as electrical performance is concerned, tube reliability is a function not alone of tube quality but also of operating conditions and circuit requirements and their relation to the tube ratings. A similar statement holds for reliability, with respect both to life and to mechanical failures. We have reached an era of highly specialized tubes. Reliability must be recognized as an equally highly specialized tube attribute.

SPECIFIC FEATURES OF MINIATURE AND SUBMINIATURE TUBES AND THEIR EFFECT ON RELIABILITY

Most of the factors affecting tube quality are encountered in varying degree in tubes of whatever size and shape. Those factors that are different in importance or magnitude in the miniature and subminiature tubes as compared to larger receiving tubes will now be discussed.

Fig. 1 shows outlines of typical bantam, miniature, and subminiature tubes. The diameters are roughly in the ratios of 3 to 2 to 1. The reductions in length are proportionately much less. They are chiefly in the electrode-to-seal distance. An important difference is in the base and lead arrangement. The bantam has a separate base, supporting contact pins to which are connected flexible leads from the stem. In the miniature, stiff contact pins are supported directly by the glass stem. In the subminiature, the leads are supported directly by the stem but are flexible. In the miniature and subminiature the exhaust tip is exposed; in the bantam it is covered by the base.

Since the miniature and subminiature tubes differ from other types primarily in the matter of size, we will look first at what effects these differences in size have on some of the major design features and the factors affecting mechanical properties.

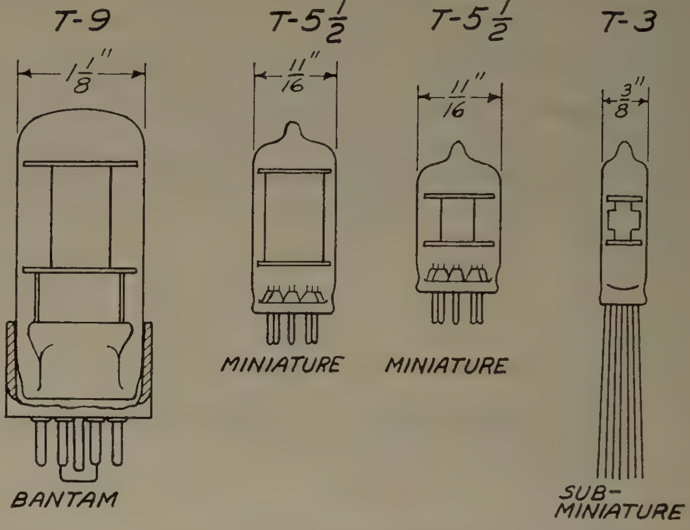

Fig. 1—Typical dimensions.

Table I lists comparative values of important dimensions for typical tubes of the bantam, miniature, and subminiature sizes. There are, of course, a variety of dimensions among the many individual tube types in each class. The figures shown are from the more commonly used types and are intended merely to be representative and not inclusive of all extreme cases.

TABLE I
RELATIVE DIMENSIONS

	T-9	T-5½	T-3
Bulb Diameter Ratios	1.125" 3.0	0.687" 1.8	0.375" 1
Bulb Length Ratios	2.4" 1.9	1.55" 1.25	1.25" 1
Spacer-to-Spacer	0.95" (1.25"–)	0.79" (1.26"–0.36")	(0.62"–0.36")
Cathode-to-Bulb Ratios	0.57" 4.1	0.29" 2.2	0.13" 1
Spacer-to-Seal Ratios	0.93" 4.9	0.31" 1.6	0.19" 1

It will be noted that percentagewise the reduction in length has been less than the reduction in diameter, and that in some of the important dimensions the subminiature is closer to the miniature than the latter is to the bantam. This is notably the case with the spacer-to-seal dimension. This has an important effect on tube processing, as will be discussed later. Attention is also called to the small absolute value of the cathode-to-bulb dimension in the subminiature. Into this space of about one-eighth inch have to be fitted from one to three grids and a plate, plus any shielding or other structural parts.

The spacer-to-spacer dimension is typically low in the subminiature. There are two basic reasons for this. The subminiature line does not include counterparts of the high-wattage types and it is made up mainly of tubes designed for high-frequency use where a short structure has important electrical advantages. Similar short structures are also used in the newer miniature tubes for the same electrical reasons, even where there is no mechanical need for them. The present subminiature designs have resulted from two simultaneous, but independent trends in application requirements: the need for smaller size, and the need for improved high-frequency performance.

It is a well-known rule that the basic electrical constants of a tube are maintained if the electrode dimensions are all scaled down in size proportionately. In a general sense, the same applies to the mechanical characteristics affecting ability to withstand shock and vibration. The ruggedness characteristics are apt to be improved by the scaling-down process. The ratios of strength to mass and moment in the grids and other parts of the structure are greater in the miniature and subminiature tubes than in the larger tubes. This was found to be the case in the early development of the proximity fuze tubes where the basic parts of the commercial subminiature hearing aid tubes were found to have adequate strength to withstand the extreme accelerations of that application. The low center of gravity of the mount, the short spacer-to-spacer distance, and the short space between grid rods are all inherently favorable for ruggedness with respect to shock. Even with the fine grid wire and close spacings of the high Gm types typical of the later miniature and the subminiature tubes, this inherent ability of the parts to withstand shock is still retained.

In the scaling-down operation one is apt to run into some dimensions that can not be scaled proportionately, and some that can be reduced below certain minimum values only with great difficulty. The distance between electrode supports, the dimensional tolerances of the holes in the mica spacers and of other parts, the length of rods extending beyond the spacers, and the space required between rods and tabs for welding are examples of these. These are items that add to the difficulty and cost of design, assembly, and control. However, it has been found possible to obtain adequate control and general freedom from mechanical troubles in the field in well-established types, such as hearing aid tubes, where millions in daily use bear witness to this.

In respect to the mechanical aspects of the glass structure, the miniature and particularly the subminiature tubes, because of small absolute size and mass, are inherently less subject to such defects as breakage by impact or handling and cracks due to glass strain. Here again, field experience with millions of tubes is notably favorable.

There is one feature of the external structure in which the miniature and the subminiature differ distinctly from the bantam. This is the type of lead. In the bantam tube flexible leads are soldered to base pins that are rigidly attached to the bulb by means of the base shell. This means that the lead is protected from handling and bending and can exert no strain on the glass structure. Of course, there are offsetting chances of basing and soldering defects. In the miniature tube the contact pins are rigid and supported only by the glass button. Any distortion or bending of the pin results in strain on the glass and, because of the rigid nature of glass, this will result in glass breakage if carried beyond a certain point. Serious field trouble from this source was encountered in the early years of miniature production. Careful control of the glass-working operations at stem making and sealing and careful control of the stiffness of the pins and proper design of the sockets have combined to reduce the glass breakage from this source to a low level.

The subminiature differs from the miniature in having small-diameter flexible leads rather than stiff pins. This is inherently a much safer combination. Here again, field experience of many years with millions of hearing aids with both solder-in and plug-in connections has demonstrated that there need be no serious trouble from this source. The button stem that permits a sharp right-angled bend of the lead at the point where it is sealed into the glass may represent a more severe condition than is present in the pinch-press seal, such as is used in most hearing aid tubes. Any weakening of the wire by overheating in stem making or sealing or by corrosion in the cleaning and tinning operation will, of course, aggravate the situation, but these conditions can be controlled so as to leave the wire in good condition. The composition of the lead wire itself is favorable to resistance to breakage by flexure and only repeated extreme flexure of the wire at a very sharp radius will cause breakage. This is apparently another situation in which recognition by the user of the inherent limitations of the tube in this respect and the adherence to suitable and practical techniques in connecting the tube in the equipment will minimize this type of failure.

A major reduction in tube size obviously introduces many problems in connection with wattage rating, bulb temperature, and quality factors involving emission, gas, and life. Table II lists comparative figures pertinent to these problems. Two items stand out conspicuously: the large percentage reduction in bulb surface area in the smaller tubes, and the large increase in permitted wattage per square inch of bulb area or, in other words, permitted bulb temperature.

There are some absolute limits on the permissible glass temperature, one being the softening point of the glass and another the point at which appreciable conductivity begins. Below these limits is an indefinite region in which varying kinds and degrees of trouble

TABLE II

BULB TEMPERATURE FACTORS

	T-9	T-5½	T-3
Bulb Area (square inches)	10.5	4.1	1.7
Ratios	6.1	2.4	1
Maximum Watts Dissipation	18.7	16.8	7.8
Ratios	2.4	2.2	1
Watts per Square Inch (averaged over area)	1.78	3.4	4.0
Ratios	0.44	0.85	1
Maximum Bulb temperature —C° (23° C ambient)	160	255	280

may be encountered, particularly from the evolution of gas and deleterious products from the glass itself, or even from the getter deposited on it. In addition, there are the accompanying effects from the higher temperature of tube parts due to high bulb temperature. Within this region, the tube design itself and the processing techniques employed in manufacture, particularly at exhaust, are important factors in determining what maximum figure for wattage dissipation, or bulb temperature, is consistent with good tube quality and life. The maximum glass temperature at any point has commonly been taken as the crucial item. The location and extent of the hot areas are also of importance. In actual practice there has been a continual trend toward higher bulb temperatures. However, the development and control of manufacturing techniques and practices have progressed in step with this trend so that, in general, the tube quality and life have been maintained.

The wattage and temperature figures shown in Table II for the T-5½ class of tube apply specifically to the 6AQ5. This tube exceeds the bounds of what had formerly been considered safe dissipation and bulb temperature. This temperature level represents approximately the upper safe limit for the present state of the art. The military services have sponsored several development projects involving studies of ways and means for increasing the permissible operating temperature. Progress in this direction is to be expected, particularly in the subminiatures, where the requirements are most severe. It may involve major changes in materials and techniques.

In Fig. 2 are shown curves relating maximum bulb temperature to average bulb dissipation. The data on which these curves are based were taken on a particular T-3 bulb and heater arrangement. As with all figures relating to the bulb temperature of radio tubes, these values should be used with caution. The temperature figures obtained or applicable in any individual case are affected to a marked degree by such factors as the details of the method of measurement, the surroundings, the heat loss through the leads, and the distribution of heat over the bulb area. The values here apply only to a particular situation, where lead conduction, for instance, was relatively low, but they may be useful in indicating approximate values likely to be encountered and the relative effects of high ambient temperatures.

In practice we have found with the 5702 subminiature series that life test at an ambient of 160°C and maximum bulb temperature of 250°C results in no appreciable deterioration of characteristics over a period of several hundred hours at least. One manufacturer has published ratings on a special line of subminiature tubes indicating at 70 per cent reduction in life for a bulb temperature of 250°C as compared to 160°C.[1] As indicated earlier, time and manufacturing and operating experience are required in determining the permissible limits and the degree of hazard involved in operating close to these limits. In any case, operation at lower and more conventional temperatures is to be recommended in cases where extreme reduction of volume is not essential and long life and reliability are the prime requirements.

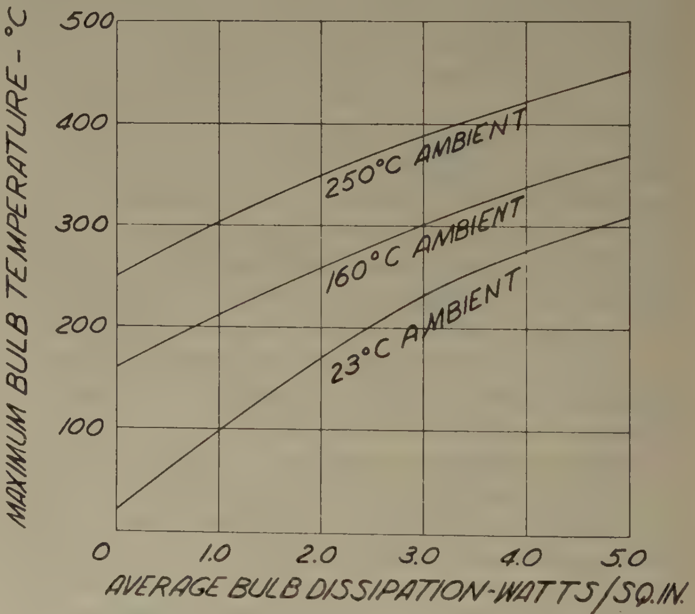

Fig. 2—Maximum bulb temperatures.

The curves of Fig. 2 indicate that operation at a high ambient and at a provenly permissible bulb temperature severely limits the wattage input. However, since the bulb temperature itself is the primary limitation, it is obvious that suitable means for increasing the rate of heat removal from the bulb will improve the situation. Metallic shields or holding clamps conductively attached to the chassis are effective and a variety of other methods are applicable. The ultimate removal of the bulb heat from the tube compartment or the chassis itself is still another problem. Any forced or conductive method of bulb cooling of course introduces the hazard of a fault in the cooling mechanism, perhaps by poor thermal contact, and consequent tube damage or failure.

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[1] As indicated by a measurement technique that would presumably give appreciably lower values than that used in obtaining the values of Table II and Fig. 2.

There are a variety of other factors of possible effect on emission and life that are altered by reduction in bulb size. Among these are such items as ratio of bulb volume and therefore total gas content to coated cathode area; ratio of bulb surface area, and therefore of one source of contamination to coated cathode area; ratio of bulb volume to exhaust tube opening, affecting pumping rate; reduced area for getter deposit; and possibility of higher and more uniform bulb temperature at exhaust. Some of these factors should be favorable to the small tubes, some unfavorable. In practice, it has been found possible to develop techniques and controls that make the over-all effects of these various minor factors relatively unimportant.

One dimension that has a notably small value in the miniature and subminiature tubes, namely, the spacer-to-seal distance, has introduced an additional processing problem. The close proximity of the cathode and other elements to the bottom seal results in increased liability to oxidation and other damaging effects from the sealing fires. The small volume and area of glass involved is a partially compensating factor. Various practical means of eliminating or minimizing these effects have been worked out and are effective when properly controlled.

In summary, it can be stated that the small tubes, miniature and subminiature, are dependent for long life, ruggedness, and reliability on the same basic design and control factors as are the larger tubes. The reduction in size has unavoidably resulted in some increased difficulty in mount assembly, tied up with the absolute size of parts. It has unavoidably resulted in different relationships between total bulb wattage and bulb temperature and has reduced the safe limit on total bulb wattage. It has improved, rather than harmed, tube ruggedness. It has introduced certain new, but controllable, items affecting quality, and has eliminated or benefited others. Small size has proved to be entirely compatible with long life and reliable performance.

Reflection and Transmission Equivalences of Dielectric Media*

R. M. REDHEFFER†

WE DEAL WITH electric media in which the properties are functions of one co-ordinate: $\epsilon/\epsilon_0=e(x)$, $\mu/\mu_0=m(x)$, $\tan\delta=l(x)$, with $e=m=1+l=1$ for $x<0$ for $x>d$. Hence, the medium is a slab of thickness d. Our first purpose is to find useful transformations of d, e, m, l, angle of incidence θ and wavelength λ under which the complex transmission T and reflection R will be invariant. Second, we show a differential equation from which T and R can be computed exactly. Typical results follow: If the polarization is perpendicular and $c=\cos\theta$, $s=\sin\theta$, then a new dielectric medium with parameters $d_1=d$, $e_1=[e(x)m(x)-s^2]/cm(x)$, $m_1=cm(x)$, $l_1=e(x)m(x)l(x)/[e(x)m(x)-s^2]$ will have the same R and T at normal incidence as the original medium had at incidence θ. Similarly if $d_1=cd$, $e_1=[\epsilon(x/c)m(x/c)-s^2]/c^2m(x/c)$, $m_1=m(x/c)$, $l_1=e(x/c)m(x/c)l(x/c)/[e(x/c)m(x/c)-s^2]$. Again, suppose $f(x)$ is any function which has at most a finite number of discontinuities and satisfies $M>f(x)>\eta$ for some positive M, η. Define $g(x)$ as the function inverse to $\int_0^x dy/f(y)$. If we construct a new sheet with parameters $d_1=\int_0^d dy/f(y)$, $e_1(x)=f[g(x)]e[g(x)]$, $m_1(x)=f[g(x)]m[g(x)]$, $l_1=l[g(x)]$, then T, R at normal incidence will be the same for the new sheet as for the original one. The reflection R satisfies the differential equation $dR/dx=(\pi iv/\lambda)[(R+1)^2a-(R-1)^2/a]$ where $\boldsymbol{\varepsilon}$ is the complex dielectric constant, $\boldsymbol{\varepsilon}=\boldsymbol{\varepsilon}(x)=e(1+il)$, $v=\sqrt{m\boldsymbol{\varepsilon}-s^2}$, and $a=\boldsymbol{\varepsilon}c/v$ (parallel polarization), $a=v/mc$ (perpendicular polarization). If $R=(z-1)/(z+1)$ then $dz/dx=(2\pi i/\lambda)(\boldsymbol{\varepsilon}z^2-1)$. The boundary conditions are evident. Other equivalences are given, including parallel polarization. The work can be used for radome design and for dielectric measurement of nonuniform samples.

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Estimating Temperature Rise in Electronic Equipment Cases*

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Summary—In the design of airborne electronic equipment of minimum size and weight, the ambient temperature rating of components is often limiting. This ambient temperature is the equilibrium temperature inside the case, and may determine either the choice of components or the need for external cooling means. Calculation of equilibrium temperature requires knowledge of the power dissipated in the case and the rate of heat transfer to the surroundings by conduction, convection, and radiation. To avoid often laborious calculation, a series of charts are presented as an aid to estimating temperature rise. Graphical corrections for pressure altitude are given, together with a discussion of the effects of case color, high-speed aircraft skin temperature, and other variables.

I. INTRODUCTION

IN SPITE OF recent developments in high-temperature electronic components, it is increasingly important for the designer to be able to estimate the component ambient temperature. This parameter determines the component life and temperature drift, and hence over-all equipment performance. Temperature rise is especially significant in equipment designed to operate in high-speed aircraft or missiles, in view of the increasing trend toward miniaturization, reduced cooling capacity of high-altitude air, and high compartment temperatures.

The steady-state temperature rise of any heat-dissipating equipment depends on the balance of power input to the case and heat lost to the surroundings. The rate of heat loss increases with some function of the temperature difference until, at equilibrium, it is equal to the equipment power dissipation.

The rate of heat input can easily be estimated by subtracting power output from power consumption. The heat lost, however, is the sum of the heat dissipated by radiation, convection, and conduction, each of which is dependent on a different function of temperature rise Δt. The heat transfer coefficients which determine the efficiency of each mode being themselves dependent on the temperature, a complicated relation exists which can only be resolved by trial and error.

In this paper an attempt has been made to supply sufficient data in the form of charts to permit designers to quickly estimate temperature rise, knowing only case size and power dissipation. If the temperature rise so obtained is too high for the components, the designer must choose a larger case size or resort to external blowers, liquid or evaporative cooling, or some other artificial cooling means, depending on system considerations.

II. RADIATION

To show how the chart values were calculated it is necessary to discuss briefly the equations governing the three modes of heat transfer. The first mode, radiation, is substantially independent of the properties of the air surrounding the case. Any body above absolute zero radiates electromagnetic energy to its surroundings in an amount proportional to the fourth power of its absolute temperature and to its "emissivity." Emissivity, being the ratio of the total radiant emissive power to that of a black body at the same temperature, may vary in value from 0 to 1. It is a fraction expressing the relative radiant cooling efficiency of surfaces. Emissivity tables may be found in McAdams[1] and other texts.

If an electronic case is completely enclosed in a compartment with walls of known temperature, the net transfer of radiant heat is proportional to the difference between absolute case and wall temperatures, each raised to the fourth power, or

$$P_r = 37e10^{-12}(T_b^4 - T_a^4) \text{ watts per square inch.} \quad (1)$$

Here P_r is the power per unit area dissipated by radiation, T_b, and T_a are the absolute case and wall temperatures, and e is the emissivity of the case. 37×10^{-12} is the Stefan-Boltzmann constant in watt-inch-°C units, expressing the relation between temperature and total energy radiated throughout the entire spectrum. A more convenient form for calculation is

$$P_r = 37e10^{-4}\left[\left(\frac{T_a + \Delta t}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right] \cdot A \text{ watts} \quad (2)$$

where Δt is the temperature difference between case and wall in °C and A the total case area in square inches. If the absolute ambient temperature T_a is known, the contribution of radiation to heat removal can be tabulated for every Δt.

III. CONVECTION

The second mode of heat removal is convection. Natural convection results from the reduction in density of the cooling medium in contact with the hot surface, leading to continuous flow of cool air past the body. In forced convection the more rapid coolant motion induced by blowers and the like results in higher rates of heat transfer. Forced convection will not be considered further, since it is the purpose of the charts to show whether such artificial cooling means, with their inherent complications and space consumption, are needed in any situation.

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† Bell Aircraft Corp., Buffalo, N. Y.

[1] W. H. McAdams, "Heat Transmission," McGraw-Hill Book Co., New York, N. Y., pp. 45–49; 1933.

In either type of convection it is assumed that a static film of fluid adheres to the surface being cooled. The heat transferred through this film can be expressed by

$$P_c = h_c \Delta t A \text{ watts,} \qquad (3)$$

where h_c is the convection heat transfer coefficient. h_c for a vertical surface can be specified further[2] as

$$h_c = Ck\left(\frac{a\Delta t}{L}\right)^{1/4}. \qquad (4a)$$

In this expression a is a function of the gravitational constant, and of the thermal expansion, density, viscosity, specific heat, and thermal conductivity k of air, the latter being all somewhat temperature-dependent. C is the product of the dimensionless Grashof and Prandtl numbers, which are also related to a, and L is the body "significant dimension." In air, at sea level and for moderate temperatures and dimensions, a simplified expression for h_c is derived from Brown and Marco[3]:

$$h_c = 0.23(\Delta t)^{1/4} \text{ BTU per square foot} \times {}^\circ\text{F} \qquad (4b)$$

which, when converted to watt-inch-°C units and substituted in (3) yields

$$P_c = 0.0010(\Delta t)^{1.25}\cdot A \text{ watts.} \qquad (5)$$

The factor (0.0010) having been variously computed as (0.0012) and (0.0014) by other authors,[4,5] the average was used for these computations. For upper and lower horizontal surfaces, experimental evidence shows that h_c increases or decreases respectively by one third, and this has been taken into account below.

It should be noted that a in (4a) is proportional to the square of the air density, or for constant temperature, to the air pressure squared. Since h_c is proportional to the fourth root of a, P_c varies with the square root of the pressure in atmospheres.

These convection coefficients are appropriate to case and wall spacings greater than $1\frac{1}{2}$ inches. When two or more cases are in close contact they may be considered as a single case.

IV. CONDUCTION

The power dissipated by conduction is

$$P = Ka\frac{\Delta t}{d} \text{ watts} \qquad (6)$$

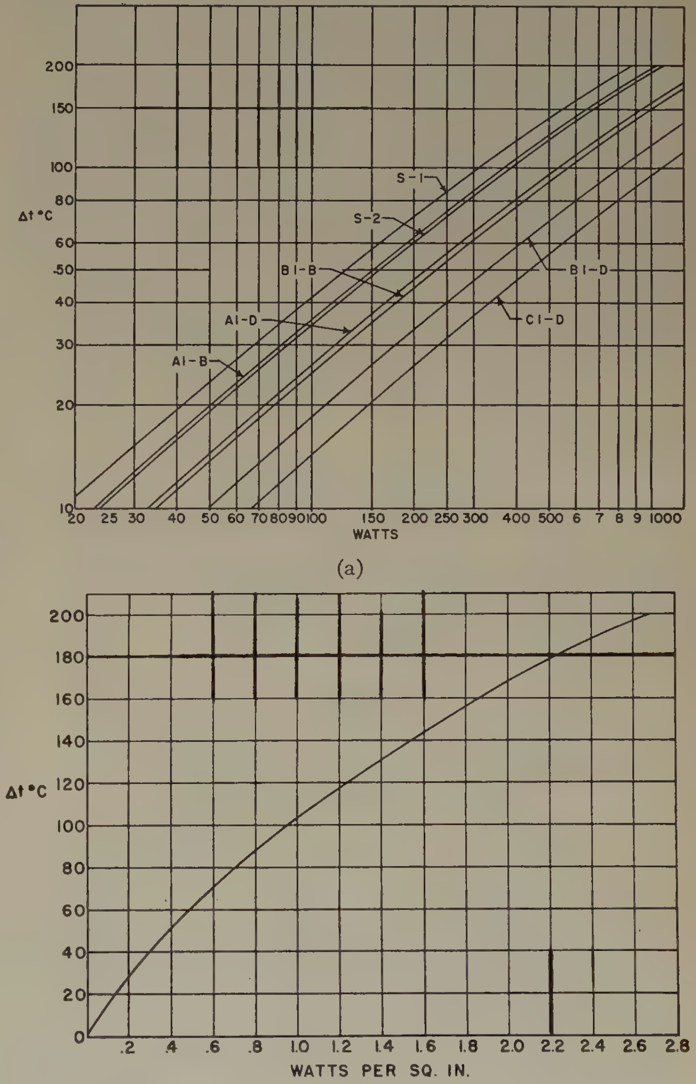
where d is the distance in inches along the conducting path. K, the coefficient of thermal conductivity, varies from 9 for copper to 0.004 for rubber. Conduction is highly important in cooling of components since intimate metal-to-metal contact can be obtained with straps, solder, and so forth. However, in the over-all cooling of an electronic case, conduction may often be neglected since, in a normally shock-mounted case, there is only a very minute heat-conducting path to the walls of the compartment. Where conduction is important, as in the case of a small unit well-bonded to a large metal frame, it can easily be included in the calculations.

V. CHART DESIGN

From the above considerations we can set up an overall equation for steady-state heat dissipation, i.e.,

$$P_{\text{total}} = A\cdot 37e10^{-4}\left[\left(\frac{T_a+\Delta t}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right] + (0.0012A_{\text{sides}} + 0.0016A_{\text{top}} + 0.0008A_{\text{bottom}})\Delta t^{1.25} \text{ watts.} \qquad (7)$$

Knowing the case size, ambient temperature, and total watts to be dissipated Δt can be calculated by trial. If a number of such calculations are to be made, a graphical solution becomes very attractive.



(a)

(b)

Fig. 1—(a) Temperature rise of JAN-C-172A cases (maximum height). (b) Temperature rise of nonstandard cases (2×2×1 inches to 18×18×18 inches).

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[2] A. I. Brown and S. M. Marco, "Introduction to Heat Transfer," McGraw-Hill Book Co., New York, N. Y., p. 115; 1942.

[3] See p. 117 of footnote reference 2.

[4] "Electronic Instruments," MIT Radiation Laboratory Series No. 21, McGraw-Hill Book Co., New York, N. Y., pp. 675–679; 1948.

[5] E. B. Steinberg, "Improved cooling of electrical devices," *Elec. Mfg.*, vol. 45, pp. 71–75; January, 1950.

Fig. 1 is such a graph calculated on the basis of the following simplifying assumptions:

1. The case is surrounded by still air at a temperature of 25°C and at normal pressure. There are no external blowers or surrounding objects closer than 1½ inches.
2. No allowance is made for conduction from the case, as would be nearly true of a case supported by rubber shock mounts. Conduction from components to case is assumed to be large.
3. The case is finished with a paint of emissivity 0.90. The compartment wall temperature is 25°C.
4. Sufficient time is allowed to achieve steady-state conditions.

From (7) and numerical values corresponding to the above assumptions the values for Fig. 1(a) were calculated. Standard JAN case sizes[6] were used to obtain the chosen values of A, and Δt values were taken from 10° to 200°C. The resulting curves, which are almost straight lines on log-log paper, enable us to find the temperature rise for the case sizes indicated by merely entering the chart with the calculated power dissipation and proceeding to the appropriate curve.

Fig. 1(b) shows the results of the same calculations for a number of arbitrary shapes, the smallest being $2\times2\times1$ inches and the largest an 18-inch cube. The results were sufficiently consistent so that all points could be plotted on a single curve if reduced to watts per square inch. Actually the points for Fig. 1(a) also fit this curve fairly well, showing that interpolation by area for JAN case sizes of less than maximum height is permissible. Fig. 1(b) can be used for any rectangular shape of reasonable dimension with a depth-to-height ratio less than 3 to 1.

VI. Effect of Altitude

The reader will recall that the convection coefficient varies with the square root of the air pressure for constant ambient temperature. Using the published data[7] for a standard atmosphere, multipliers for P_c can be easily obtained, as in Table I.

TABLE I

Altitude (Thousands of feet)	Multiplier for P_c
20	0.625
40	0.428
80	0.166
100	0

At about 35,000 feet the amount of convection cooling drops to one half, and above 100,000 feet cooling must occur entirely by radiation.

We would expect that the ratio of convected to radiated power would change for each temperature difference, since one depends on the 1.25 power and the other with the fourth power of Δt. However, when the tabulated values used to obtain Fig. 1 were compared, it was found that the convected power was very close to 40 per cent of the total for all case sizes and for Δt between 20° and 150°C. Thus it is possible to make a single correction curve for altitude by simply multiplying this 40 per cent by the factors of Table I and adding to the 60 per cent contribution of radiation.

In Fig. 2 is shown a plot of the ratio of the dissipation at the indicated altitude to the sea-level dissipation required to maintain a temperature rise in the above range. For instance, at 60,000 feet the ratio is 0.71; hence, a 100-watt unit having a Δt of 40° at sea level would have the same temperature rise when dissipating 71 watts at 60,000 feet. Similarly, to find the temperature rise of an equipment with a fixed power dissipation at any altitude, we enter Fig. 2 to find the wattage ratio for that altitude. Dividing the power dissipation by the ratio an "equivalent sea-level power" is found, which when used to enter Fig. 1, yields the required Δt at altitude. For example, a unit dissipating 100 watts in a JAN size A1–B case would, at sea level, from Fig. 1(a), have a Δt of 36°. If it is to be used at 60,000 feet, Fig. 2 is entered to obtain a factor of 0.71. Dividing the actual power 100 by this factor, yields 141 watts of equivalent sea-level power. Using this to enter Fig. 1(a) again, Δt is found to be 48°, an increase of 12° or 33 per cent.

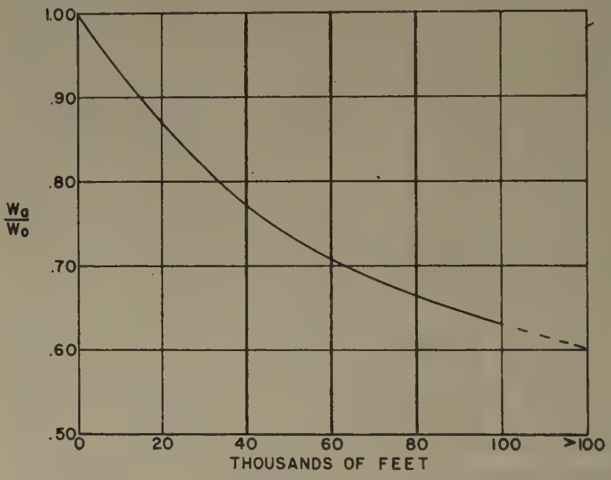

Fig. 2—Fraction of actual wattage W_0 to maintain constant temperature rise at any altitude.

VII. Surface and Color

The effects of surface treatment and color are more difficult to evaluate generally that those of altitude, since any change in the surface may change the emissivity significantly. There is, further, not too much correlation between visible color and emissivity, since most of the energy radiated at low temperatures is in the infrared region. At high altitudes, where radiation is the major cooling means, a change in case surface may increase its temperature rise many times.

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[6] "Cases and Mounting Bases, Electronic, Aircraft," Nat. Mil. Est. Spec., Figs. 1 and 4; June 15, 1949.

[7] W. S. Diehl, "Standard Atmosphere Tables and Data," NACA Technical Report 218, U. S. Gov't. Printing Office, Washington, D. C.; 1940.

Fig. 3 is a comparison of the sea-level temperature rise of a bright aluminum case, emissivity 0.04, compared with one coated with a paint of emissivity 0.90. The temperature rise of the former at 40,000 feet is also shown. The sea-level rise for the aluminum case is nearly twice that of the painted one, while at 40,000 feet the increase is well over three times. Although this figure was calculated for only one case size, the ratios indicated hold for any size and Δt in the range considered.

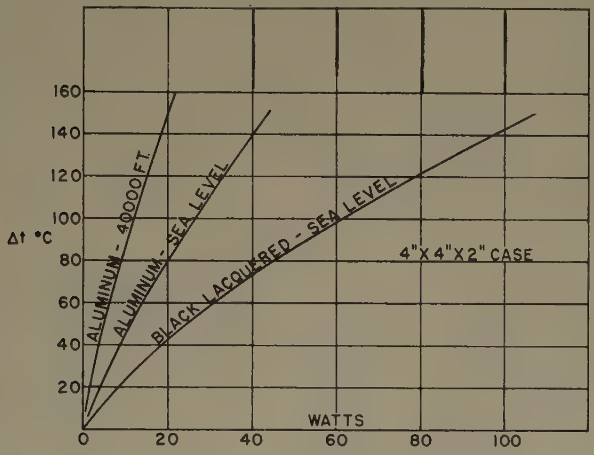

Fig. 3—Effect of case surface on temperature rise.

VIII. Effect of Conduction

It was mentioned that no account was taken of conduction in obtaining the values for Fig. 1. Since radiation and convection were included for the bottom of the case, conduction causes little change in Δt, except where good metallic contact exists between case and rack. Where conduction is considered important, it can be included as follows: First, the Δt is determined as above. Using this value, the conducted power is calculated using (6) with appropriate values for K, A, and d. Subtracting this value from the actual heat dissipation, a new Δt is found. It should not be necessary to repeat this process more than once.

IX. Louvers, Slots, and Blowers

At sea level, the temperature rise estimated from Fig. 1 can be reduced one third by the use of well-designed louvers.[4] Since the volumetric heat capacity of air is proportional to its density, and hence to the pressure altitude, the heat removed through the louvers should be less by this factor. Table II gives the percentage deduction from Δt estimated by Figs. 1 and 2, due to the use of louvers. It can be seen that louvers are comparatively ineffective at high altitudes, though they work very well at sea level.

TABLE II

Altitude (Thousands of Feet)	Percentage Deduction from Δt due to Louvers
0	33
20	15
40	6

The use of blowers and baffles to reduce hot spots serves to increase the validity of Fig. 1, since it was calculated on the assumption of good heat transfer from components to the case wall. When using them, it must be remembered that the power consumption of the blower must be included in the heat load. Outside blowers represent a case of forced convection, which has not been considered; however, Table II can be used to estimate the change in efficiency of constant-volume blowers with altitude.

X. An Experimental Check

Although the heat transfer coefficients used to calculate the figures have been verified many times, it was considered of interest to make a check for the conditions presented. Fig. 4 shows the results of a few measurements on a standard black crackle-finish case 6×6×6 inches. The case was supported on wooden blocks and the power dissipation varied by means of resistors fastened to the inner surfaces. The experimental points are the average of all six surfaces and the solid line is calculated as in Fig. 1(b). The agreement is apparently good, while the slight decrease from the calculated values may be taken as an indication of conduction through the wooden blocks.

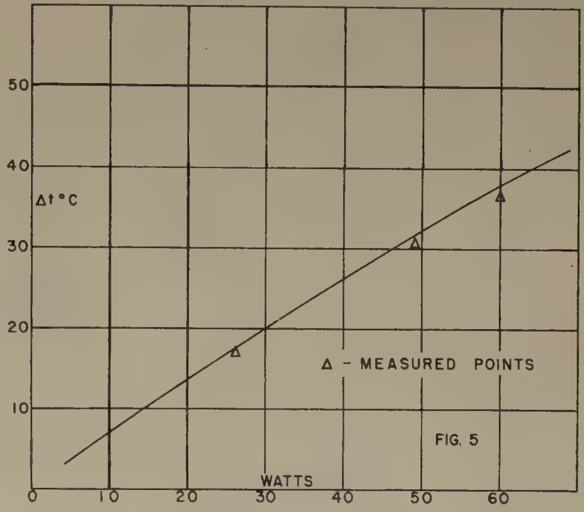

Fig. 4—Temperature versus power input 6×6×6 inches black case, sea level 25° ambient.

XI. High Ambient Temperatures

Since Fig. 1 was obtained on the assumption of 25°C ambient, a correction must be applied for warmer air, as it is less dense and has lesser cooling capacity. Over the range of 10° to 50°C ambient, it has been stated[4] that Δt increases about 10 per cent.

An important case of increased ambient is found in the high skin temperature of modern aircraft and missiles. The actual computation of skin temperature is beyond the scope of this paper, since the calculation is usually based on transient considerations. For the electronic equipment designer, it may be sufficient to consider only the maximum possible steady-state temperature to which the skin could rise.

If an airframe is considered to carry with it a boundary layer of air which is motionless or at low velocity relative to its skin, it can be shown that the temperature of this layer is higher than that of the external ambient air mass. The boundary layer, or "adiabatic wall" temperature is dependent on the Mach number of the airframe and on the external air-mass temperature. If there were no heat gains or losses by radiation or other cause, the skin would eventually reach the boundary layer temperature, which can be simply expressed by

$$T_{BL} = T_A(1 + 0.18M^2). \tag{8}$$

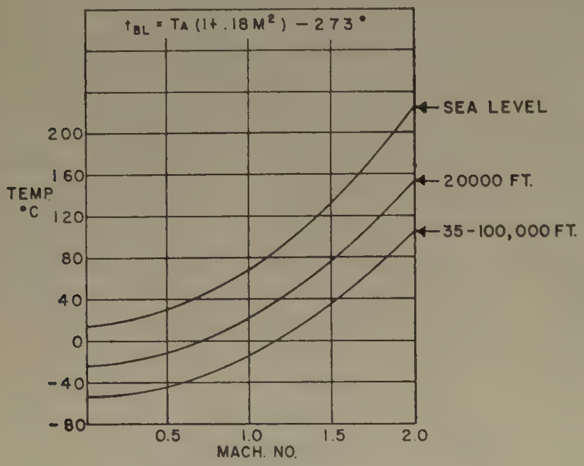

Fig. 5—Boundary layer temperature.

T_{BL} and T_A represent the absolute temperatures of the boundary layer and ambient air mass, while M is the Mach number. The factor 0.18 results from consideration of the adiabatic change in state of the air entering the boundary layer, corrected by a "recovery factor" allowing for deviations from adiabatic.

Fig. 5 shows the values of boundary-layer temperature for a range of Mach numbers and altitudes. It is seen that the temperature rises very rapidly with Mach number, exceeding 100°C at Mach 2 even at 35,000 feet. The figure demonstrates that little reliance can be placed on the low ambient temperatures existing at high altitude for cooling electronic equipment in very high speed aircraft or missiles.

XII. CONCLUSION

The charts derived from theoretical and experimentally verified heat-transfer coefficients can be used to estimate average temperature rise in electronic cases operating on the ground and in aircraft. Many factors cannot be so estimated, since the charts do not take into account thermally insulated heat sources or hot spots. They should prove time-saving and useful if restricted to their primary purpose of permitting a rational choice of case size, and if followed by adequate hot-spot exploration under actual or simulated flight conditions.

ACKNOWLEDGMENTS

The author expresses appreciation to the following members of the engineering staff of the Bell Aircraft Corporation: Charles J. Rife who suggested the need for such an analysis, and Richard Passman for helpful criticism of the original paper and, in particular, the aerodynamic section. Ernest Metzger performed the experimental work for Fig. 4.

CORRECTION

N. A. Begovich, author of the paper, "Slot Radiators," which appeared on pages 803–807, of the July, 1950, issue of the PROCEEDINGS OF THE I.R.E., has written to the editors regarding his paper as follows:

"In discussing my paper, 'Slot Radiators,' with my colleagues, I have noticed an inconsistency between equations (11) and (12). The definition given by (11) for Poynting's vector: namely, using the conjugate of H, requires that the conjugate of Y_1^s appears in the right side of (12). This follows directly from the derivation of Poynting's theorem. Consequently, the asterisks that appear in equations (13), (14), and (16) should be removed and a minus sign should be placed before the j in (15).

"It probably should be emphasized that since the equivalent circuit for a slot array of two or more slots is a 'pi' network, the only meaning for Z_m^{2s} given in section IV is that it is the reciprocal of the mutual admittance Y_m^{2s}. In discussing an individual slot, its admittance or impedance can be used interchangeably. However, in discussing the mutual coupling between slots, (16) relates the mutual admittance of the slots to the corresponding mutual impedance between wire antennas. This is clearly illustrated when the calculation is performed as indicated in the first sentence of section IV."

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Standards on Electroacoustics: Definitions of Terms, 1951*

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Ac Erasing Head. In magnetic recording, one which uses alternating current to produce the magnetic field necessary for erasing.

Note—AC erasing is achieved by subjecting the medium to a number of cycles of a magnetic field of a decreasing magnitude. The medium is, therefore, essentially magnetically neutralized.

AC Magnetic Biasing. In magnetic recording, magnetic biasing accomplished by the use of an alternating current, usually well above the signal frequency range.

Absorption Loss. That part of the transmission loss due to the dissipation or conversion of sound energy into other forms of energy (e.g., heat), either within the medium or attendant upon a reflection.

Acceleration. The time rate of change of velocity.

Acetate Disks. Mechanical recording disks, either solid or laminated, which are made of various acetate compounds.

Acoustic.[1] When used as a qualifying term denotes containing, producing, arising from, actuated by, or carrying sound, or designed to carry sound and capable of doing so.

Examples: acoustic horn, transducer, energy, wave, impedance.

Acoustic Compliance.[2] The reciprocal of acoustic stiffness. Its dimensions are $M^{-1}L^4T^2$.

Acoustic Dispersion. The separation of a complex sound wave into its various frequency components, usually caused by a variation with frequency of the wave velocity of the medium. The rate of change of the velocity with frequency is used as a measure of the dispersion.

Acoustic Generator. A transducer which converts electric, mechanical, or other forms of energy into sound.

Acoustic Horn (Horn). A tube of varying cross section having different terminal areas which provide a change of acoustic impedance and control of the directivity pattern.

Acoustic Impedance. The acoustic impedance of a sound medium on a given surface lying in a wave front is the complex quotient of the sound pressure (force per unit area) on that surface by the flux (volume velocity, or linear velocity multiplied by the area), through the surface. When concentrated, rather than distributed, impedances are considered, the impedance of a portion of the medium is defined by the complex quotient of the pressure difference effective in driving that portion, by the flux (volume velocity). The acoustic impedance may be expressed in terms of mechanical impedance, acoustic impedance being equal to the mechanical impedance divided by the square of the area of the surface considered. The commonly used unit is the acoustical ohm.

Note 1—Velocities in the direction along which the impedance is to be specified are considered positive.

Note 2—The terms and definitions to which this note is appended pertain to single-frequency quantities in the steady state, and to systems whose properties are independent of the magnitudes of these quantities.

Acoustic Interferometer. An instrument for measuring the velocity or frequency of sound waves in a liquid or gas by observing the variations of sound pressure in a standing wave established in the medium between a sound source and a reflector, as the reflector is moved or the frequency is varied.

Acoustic Mass (Acoustic Inertance). The quantity which, when multiplied by 2π times the frequency, gives the acoustic reactance associated with the kinetic energy of the medium. The commonly used unit is the gram per centimeter to the fourth power. Its dimensions are ML^{-4}.

Acoustic Pickup (Sound Box). A device which transforms groove modulations directly into acoustic vibrations.

Acoustic Radiating Element. A vibrating surface in a transducer which can cause or be actuated by sound waves.

Acoustic Radiometer. An instrument for measuring sound intensity by determining the unidirectional steady-state pressure caused by the reflection or absorption of a sound wave at a boundary.

Acoustic Reactance.[2] The imaginary component of the acoustic impedance. The commonly used unit is the acoustical ohm.

Acoustic Refraction. The variation of the direction of sound transmission due to spatial variation of the wave velocity in the medium.

Acoustic Resistance.[2] The real component of the acoustic impedance. The commonly used unit is the acoustical ohm.

Acoustic Scattering. The irregular and diffuse reflection or diffraction of sound in many directions.

Note—Scattering frequently occurs when the reflecting surfaces or bodies are small compared with the wavelength of sound; in certain cases the reflecting bodies may be small inhomogeneities in the medium.

Acoustic Stiffness.[2] The quantity which, when divided by 2π times the frequency, gives the acoustic reactance associated with the potential energy of the medium or its boundaries. The unit commonly used is the dyne per centimeter to the fifth power. Its dimensions are $ML^{-4}T^{-2}$.

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[1] This usage of "acoustic" and "acoustical" as modifiers agrees with the commonly accepted usage of "electric" and "electrical." In the science of mechanics, however, the term "mechanical" is the only modifier in common use.

[2] See Note 2 under **Acoustic Impedance.**

Acoustic Transmission System. An assembly of elements adapted for the transmission of sound.

Acoustical.[3] When used as a qualifying term denotes related, pertaining to, or associated with sound, but not having its properties or characteristics.

Examples: acoustical engineer, school, glossary, unit.

Acoustical Ohm.[2] An acoustic resistance, reactance, or impedance has a magnitude of one acoustical ohm when a sound pressure of 1 microbar produces a volume velocity of 1 cubic centimeter per second.

Acoustical Reciprocity Theorem. In an acoustic system comprising a fluid medium having bounding surfaces S_1, S_2, S_3, $\cdots$, and subject to no impressing body forces, if two distributions of normal velocities v_n' and v_n'' of the bounding surfaces produce pressure fields p' and p'', respectively, throughout the region, then the surface integral of $(p''v_n' - p'v_n'')$ over all the bounding surfaces S_1, S_2, S_3, $\cdots$, vanishes.

Note—If the region contains only one simple source, the theorem reduces to the form ascribed to Helmholtz, viz., in a region as described, a simple source at A produces the same sound pressure at another point B as would have been produced at A had the source been located at B.

Acoustical Units. In acoustics, the centimeter-gram-second (cgs) system of units has been and is at present predominantly used; but some practical units such as English and metric system units of length are also being used; and the watt is commonly being employed for designating acoustic power. In recent years, there has been a trend toward adoption of the rationalized meter-kilogram-second system of units in many fields of science and engineering. It would, of course, be highly desirable if, in place of the present diversity and mixture of scientific units, a single system of units could be universally used. While the mks units so far have not been employed in acoustics, if there is a trend toward their universal adoption, the workers in the field of acoustics will want to follow suit. For this reason, the table below for the conversion of present acoustical units into mks units is being presented.

Acoustics. The science of sound including its production, transmission, and effects.

Advance Ball. In mechanical recording, a rounded support (often sapphire) attached to a cutter which rides on the surface of the recording medium so as to maintain a uniform mean depth of cut and correct for small irregularities of the disk surface.

Aeolight. A glow lamp employing a cold cathode and a mixture of permanent gases in which the intensity of illumination varies with the applied signal voltage.

Air Condution. The process by which sound is conducted to the inner ear through the air in the outer ear canal as part of the pathway.

Angular Deviation Loss. Of a transducer used for sound emission or reception, an expression, in decibels, of the ratio of the reference response observed on the principal axis to the transducer response at a specified angle from the principal axis.

See also: **Directivity Pattern (Directional Response Pattern) (Beam Pattern).**

Antinoise Microphone. A microphone with characteristics which discriminate against acoustic noise.

Applied Shock. Any excitation which, if applied to a system, would produce shock motion within the system.

Articulation (Per Cent Articulation) and Intelligibility (Per Cent Intelligibility). Of a communication system, the percentage of the speech units spoken by a talker or talkers that is understood correctly by a listener or listeners.

The word "articulation" is customarily used when the contextual relations among the units of the speech ma-

TABLE I

CONVERSION OF PRESENT ACOUSTICAL UNITS INTO MKS UNITS

Quantity	*Dimension*	*Present Unit*	*MKS Unit*	*Conversion Factor**
Sound velocity (particle velocity)	LT^{-1}	cm per second	meter per second	10^{-2}
Volume velocity	L^3T^{-1}	cubic cm per second	cubic meter per second	10^{-6}
Sound energy	ML^2T^{-2}	erg	joule	10^{-7}
Force	MLT^{-2}	dyne	newton	10^{-5}
Sound pressure (sound-energy density)	$ML^{-1}T^{-2}$	microbar	newton per square meter	10^{-1}
Sound energy flux (sound power of source)	ML^2T^{-3}	erg per second	watt	10^{-7}
Sound intensity (specific sound-energy flux)	MT^{-3}	erg per second per square cm	watt per square meter	10^{-3}
		watt per square cm		10^4
Acoustic impedance (resistance, reactance)	$ML^{-4}T^{-1}$	acoustical ohm	mks acoustical ohm	10^5
Specific acoustic impedance	$ML^{-2}T^{-1}$	acoustical ohm×square cm	mks acoustical ohm† ×square meter	10
Mechanical impedance (resistance, reactance)	ML^{-1}	mechanical ohm	mks mechanical ohm†	10^{-3}

* Multiply the magnitude expressed in present units by the tabulated conversion factor to obtain magnitude in mks units.
† MKS acoustical ohm and mks mechanical ohm are proposed terms.

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[3] This usage of "acoustic" and "acoustical" as modifiers agrees with the commonly accepted usage of "electric" and "electrical." In the science of mechanics, however, the term "mechanical" is the only modifier in common use.

terial are thought to play an unimportant role; the word "intelligibility" is customarily used when the context is thought to play an important role in determining the listener's perception.

Note 1—It is important to specify the type of speech material and the units into which it is analyzed for the purpose of computing the percentage. The units may be fundamental speech sounds, syllables, words, sentences, and so forth.

Note 2—The per cent articulation or per cent intelligibility is a property of the entire communication system; talker, transmission equipment or medium, and listener. Even when attention is focused upon one component of the system (e.g., a talker, a radio receiver), the other components of the system should be specified.

Artificial Ear. A device for the measurement of earphones which presents an acoustic impedance to the earphone equivalent to the impedance presented by the average human ear. It is equipped with a microphone for measurement of the sound pressures developed by the earphone.

Artificial Voice. A small loudspeaker mounted in a shaped baffle which is proportioned to simulate the acoustical constants of the human head. The artificial voice is used for calibrating and testing close-talking microphones.

Audio Frequency. Any frequency corresponding to a normally audible sound wave.

Note 1—Audio frequencies range roughly from 15 to 20,000 cycles per second.

Note 2—The word "audio" may be used as a modifier to indicate a device or system intended to operate at audio frequencies, e.g., "audio amplifier."

Audiogram (Threshold Audiogram). A graph showing hearing loss, per cent hearing loss, or per cent hearing as a function of frequency.

Audiometer. An instrument for measuring hearing acuity. Measurements may be made with speech signals, usually recorded, or with tone signals.

Note—Specifications for a pure tone audiometer for general diagnostic purposes are covered by "Proposed American Standard Specification for Audiometers for General Diagnostic Purposes, Z24.5/158."

Auditory Sensation Area. (1) The region enclosed by the curves defining the threshold of feeling and the threshold of audibility as functions of frequency. (2) The part of the brain (temporal lobe of the cortex) which is responsive to auditory stimuli.

Aural Harmonic. A harmonic generated in the auditory mechanism.

Available Power. (a) The available power of a linear source of electric energy is the quotient of the mean square of the open-circuit terminal voltage of the source divided by four times the resistive component of the impedance of the source.

Note—The available power would be delivered to a load impedance that is the conjugate of the internal impedance of the source, and is the maximum power that can be delivered by that source.

(b) The available power of a sound field, with respect to a given object placed in it, is the power which would be abstracted from the acoustic medium by an ideal transducer having the same dimensions and the same orientation as the given object. The dimensions and their orientation with respect to the sound field must be specified. The commonly used unit is the erg per second but the available power may also be expressed in watts.

Note—The acoustic power available to an electroacoustic transducer, in a plane-wave sound field of given frequency, is the product of the free-field sound intensity by the effective area of the transducer.

For this purpose the effective area of an electroacoustic transducer, for which the surface velocity distribution is independent of the manner of excitation of the transducer, is $1/4\pi$ times the product of the receiving directivity factor by the square of the wavelength of a free progressive wave in the medium. The commonly used unit is the square centimeter.

If the physical dimensions of the transducer are small in comparison with the wavelength, the directivity factor is near unity, and the effective area varies inversely as the square of the frequency. If the physical dimensions are large in comparison with the wavelength, the directivity factor is nearly proportional to the square of the frequency, and the effective area approaches the actual area of the active face of the transducer.

Available Power Efficiency. Of an electroacoustic transducer used for sound reception, the ratio of the electric power available at the electric terminals of the transducer to the acoustic power available to the transducer.

Note 1—For an electroacoustic transducer which obeys the reciprocity principle, the available power efficiency in sound reception is equal to the transmitting efficiency.

Note 2—In a given narrow frequency band the available power efficiency is numerically equal to the fraction of the open-circuit mean-square thermal noise voltage present at the electric terminals which is contributed by thermal noise in the acoustic medium.

Available Power Response. Of an electroacoustic transducer used for sound emission, the ratio of the mean-square sound pressure apparent at a distance of 1 meter in a specified direction from the effective acoustic center of the transducer to the available electric power from the source. The available power response is usually expressed in decibels above the reference response of 1 microbar squared per watt of available electric power.

Note 1—The sound pressure apparent at a distance of 1 meter is determined by multiplying the sound pressure observed at a remote point where the sound field is spherically divergent by the ratio of the distance of that point, in meters, from the effective acoustic center of the transducer, to the reference distance of 1 meter.

Note 2—The available power response is a function not only of the transducer but also of some source impedance, either actual or hypothetical, the value of which must be specified.

Backed Stamper. In mechanical recording, a thin metal stamper which is attached to a backing material, generally a metal disk of desired thickness.

Background Noise. In recording and reproducing, the total system noise independent of whether or not a signal is present. The signal is not be included as part of the noise.

Baffle. A shielding structure or partition used to increase the effective length of the external transmission path between two points in an acoustic system as for example, between the front and back of an electroacoustic transducer.

Note—In the case of a loudspeaker, a baffle is often used to increase the acoustic loading of the diaphragm.

Band Pressure Level. The band pressure level of a sound for a specified frequency band is the effective sound pressure level for the sound energy contained within the band. The width of the band and the reference pressure must be specified.

Note—When measuring thermal noise, the standard deviation of the sound pressure readings will not exceed about 10 per cent if the product of the bandwidth in cycles per second and the integration time in seconds exceeds 20.

Basic Frequency. Of an oscillatory quantity having sinusoidal components with different frequencies, the frequency of the component considered to be the most important.

Note—In a driven system, the basic frequency would, in general, be the driving frequency, and in a periodic oscillatory system, it would be the fundamental frequency.

Bidirectional Microphone. A microphone in which the response predominates for sound incidences of 0° and 180°.

See also: **Principal Axis.**

Bilateral-Area Track. A photographic sound track having the two edges of the central area modulated according to the signal.

Binder. A resinous material which causes the various materials of a record compound to adhere to one another.

Blocked Impedance.[2] Of a transducer, the impedance at the input when the impedance of the output system is made infinite.

Note—For example, in the case of an electromechanical transducer, the blocked electric impedance is the impedance measured at the electric terminals when the mechanical system is blocked or clamped; the blocked mechanical impedance is measured at the mechanical side when the electric circuit is open-circuited.

Bone Conduction. The process by which sound is conducted to the inner ear through the cranial bones.

Burnishing Surface. In mechanical recording, the portion of the cutting stylus directly behind the cutting edge which smooths the groove.

Cake Wax. A thick disk of wax upon which an original mechanical disk recording may be inscribed.

Capacitor Pickup. A phonograph pickup which depends for its operation upon the variation of its electric capacitance.

Carbon Microphone. A microphone which depends for its operation upon the variation in resistance of carbon contacts.

Cavitation. The formation of local cavities in a liquid as a result of the reduction of total pressure.

Cent. The interval between two sounds whose basic frequency ratio is the twelve-hundredth root of two.

Note—The interval, in cents, between any two frequencies is 1,200 times the logarithm to the base 2 of the frequency ratio. Thus 1,200 cents = 12 equally tempered semitones = 1 octave.

TABLE II

SOME JUST INTERVALS

(See "Just Scale")

Name of Interval	*Frequency Ratio*	*Cents*
Unison	1:1	
Semitone	16:15	111.731
Minor tone or lesser whole tone	10:9	182.404
Major tone or greater whole tone	9:8	203.910
Minor third	6:5	315.641
Major third	5:4	386.314
Perfect fourth	4:3	498.045
Augmented fourth	45:32	590.224
Diminished fifth	64:45	609.777
Perfect fifth	3:2	701.955
Minor sixth	8:5	813.687
Major sixth	5:3	844.359
Harmonic minor seventh	7:4	968.826
Grave minor seventh	16:9	996.091
Minor seventh	9:5	1,017.597
Major seventh	15:8	1,088.269
Octave	2:1	1,200.000

Chip. In mechanical recording, the material removed from the recording medium by the recording stylus while cutting the groove.

Class-A Push-Pull Sound Track. A class-A push-pull photographic sound track consists of two single tracks

TABLE III

Some Small Intervals

Name of Interval	Description	Frequency Ratio	Cents
Comma of Didymus	excess of greater whole tone over lesser whole tone	81:80	21.506
Comma of Pythagoras	excess of 12 Pythagorean fifths over 7 octaves	531441:524882	23.460
Skhisma	excess of Pythagorean over Didymean comma (almost exactly equal to the difference between a Pythagorean and an equally tempered perfect fifth	32805:32768	1.954

side by side, the transmission of one being 180° out of phase with the transmission of the other. Both positive and negative halves of the sound wave are linearly recorded on each of the two tracks.

Class-B Push-Pull Sound Track. A class-B push-pull photographic sound track consists of two tracks side by side, one of which carries the positive half of the signal only, and the other the negative half. During the inoperative half cycle, each track transmits little or no light.

Close-Talking Microphone. A microphone designed particularly for use close to the mouth of the speaker.

Combination Microphone. A microphone consisting of a combination of two or more dissimilar microphones.

Note—Examples of combination microphones are: two oppositely phased pressure microphones acting as a gradient microphone, and a pressure microphone and a velocity microphone acting as a unidirectional microphone.

Complex Tone. (1) A sound wave produced by the combination of simple sinusoidal components of different frequencies.

(2) A sound sensation characterized by more than one pitch.

Compressional Wave. A wave in an elastic medium which causes an element of the medium to change its volume without undergoing rotation.

Note 1—Mathematically, a wave whose intensity field has zero curl.

Note 2—A compressional plane wave is a longitudinal wave.

TABLE IV

Equally Tempered Intervals

(See "Equally Tempered Scale")

Name of Interval	Frequency Ratio	Cents
Unison	1:1	0
Minor second or semitone	1.059463:1	100
Major second or whole tone	1.122462:1	200
Minor third	1.189207:1	300
Major third	1.259921:1	400
Perfect fourth	1.334840:1	500
Augmented fourth Diminished fifth	1.414214:1	600
Perfect fifth	1,498307:1	700
Minor sixth	1.587401:1	800
Major sixth	1.681793:1	900
Minor seventh	1.781797:1	1,000
Major seventh	1.887749:1	1,100
Octave	2:1	1,200

Conical Horn. A horn whose cross-sectional area increases as the square of the axial length.

Constant Amplitude Recording. A mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is independent of frequency.

Constant Velocity Recording. A mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is inversely proportional to the frequency.

Control Track. A supplementary sound track, usually placed on the same film with the sound track carrying the program material. Its purpose is to control, in some respect, the reproduction of the sound track. Ordinarily, it contains one or more tones, each of which may be modulated either as to amplitude or frequency.

Core. In mechanical recording, the central layer or basic support of certain types of laminated media.

Crossover Frequency. As applied to electric dividing networks, the crossover frequency is the frequency at which equal electric powers are delivered to each of the adjacent frequency channels when all channels are terminated in the loads specified.

See also: **Transition Frequency (Crossover Frequency).**

Crystal Cutter. A cutter in which the mechanical displacements of the recording stylus are derived from the deformations of a crystal having piezoelectric properties.

Crystal Loudspeaker (Piezoelectric Loudspeaker). A loudspeaker in which the mechanical displacements are produced by piezoelectric action.

Crystal Microphone (Piezoelectric Microphone). A microphone which depends for its operation on the generation of an electric charge by the deformation of a body (usually crystalline) having piezoelectric properties.

Crystal Pickup (Piezoelectric Pickup). A phonograph pickup which depends for its operation on the generation of an electric charge by the deformation of a body (usually crystalline) having piezoelectric properties.

Cutter. An electromechanical transducer which transforms an electric input into a mechanical output, typified by mechanical motions which may be inscribed into a recording medium by a cutting stylus.

Cutting Stylus.[4] A recording stylus with a sharpened tip which, by removing material, cuts a groove into the recording medium.

DC Erasing Head. In magnetic recording, one which uses direct current to produce the magnetic field necessary for erasing.

Note—DC erasing is achieved by subjecting the medium to a undirectional field. Such a medium is, therefore, in a different magnetic stage than one erased by alternating current.

DC Magnetic Biasing. In magnetic recording, magnetic biasing accomplished by the use of direct current.

Dead Room. A room which is characterized by an unusually large amount of sound absorption.

De-emphasis (Postemphasis) (Post equalization). A form of equalization complementary to pre-emphasis.

Densitometer. An instrument for the measurement of optical density (photographic transmission, photographic reflection, visual transmission, and so forth) of a material.

Difference Limen (Differential Threshold) (Just Noticeable Difference). The increment in a stimulus which is just noticed in a specified fraction of the trials. The relative difference limen is the ratio of the difference limen to the absolute magnitude of the stimulus to which it is related.

Diffracted Wave. When a wave in a medium of certain propagation characteristics is incident upon a discontinuity or a second medium, the diffracted wave is the wave component that results in the first medium in addition to the incident wave and the waves corresponding to the reflected rays of geometrical optics.

Diffraction. That process which produces a diffracted wave.

Diffuse Sound. In a given region, sound which has uniform energy density and is such that all directions of energy flux at all parts of the region are equally probable.

Diffuse Transmission Density.[5] The value of the photographic transmission density obtained when the light flux impinges normally on the sample and all the transmitted flux is collected and measured.

Direct Radiator Loudspeaker. A loudspeaker in which the radiating element acts directly on the air.

Directional Microphone. A microphone the response of which varies significantly with the direction of sound incidence.

Directivity Factor. (a) The directivity factor of a transducer used for sound emission is the ratio of the intensity of the radiated sound at a remote point in a free field on the principal axis to the average intensity of the sound transmitted through a sphere passing through the remote point and concentric with the transducer. The frequency must be stated.

Note 1—The point of observation must be sufficiently remote from the transducer for spherical divergence to exist.

Note 2—This definition may be extended to cover the case of finite frequency bands whose spectrum must be specified.

(b) The directivity factor of a transducer used for sound reception is the ratio of the square of the electromotive force produced in response to sound waves arriving in a direction parallel to the principal axis to the mean square of the electromotive force that would be produced if sound waves having the same frequency and mean-square pressure were arriving at the transducer simultaneously from all directions with random phase. The frequency must be stated.

Note 1—For an electroacoustic transducer obeying the reciprocity principle, the directivity factor for sound reception is the same as for sound emission.

Note 2—This definition may be extended to cover the case of finite frequency bands whose spectrum must be specified.

Note 3—Directivity factor in acoustics is equivalent to directivity as applied to antennas.

Directivity Index (Directional Gain). Of a transducer, an expression of the directivity factor in decibels, viz., 10 times the logarithm to the base 10 of the directivity factor.

Directivity Pattern (Directional Response Pattern) (Beam Pattern). Of a transducer used for sound emission or reception, a description, often presented graphically, of the response of the transducer as a function of the direction of the transmitted or incident sound waves in a specified plane and at a specified frequency.

Note 1—A complete description of the directivity pattern of a transducer would require three-dimensional presentation.

Note 2—The directivity pattern is often shown as the response relative to the maximum response.

Discrete Sentence Intelligibility.[6] The per cent intelligibility obtained when the speech units considered are sentences (usually of simple form and content).

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[4] Stylus is a term defining a pickup needle or holder furnished with a jewel or other abrasive-resistant tip. A stylus may or may not be arranged for convenient replacement.

[5] For details of measurement and specifications see "American Standard Diffuse Transmission Density, Z38.2.5–1946," or the latest edition thereof approved by the American Standards Association.

[6] See notes under **Articulation (Per Cent Articulation) and Intelligibility (Per Cent Intelligibility).**

Discrete Word Intelligibility.[6] The per cent intelligibility obtained when the speech units considered are words (usually presented so as to minimize the contextual relation between them).

Disk Recorder. A mechanical recorder in which the recording medium has the geometry of a disk.

Divergence Loss. That part of the transmission loss which is due to the divergence or spreading of the sound rays in accordance with the geometry of the system (e.g., spherical waves emitted by a point source).

Dividing Network (LS Dividing Network). A frequency selective network which divides the spectrum to be radiated into two or more parts.

Doppler Effect. The phenomenon evidenced by the change in the observed frequency of a wave in a transmission system caused by a time rate of change in the effective length of the path of travel between the source and the point of observation.

Doppler Shift. The magnitude of the change in the observed frequency of a wave due to the Doppler effect. The unit is the cycle per second.

Double Pole-Piece Magnetic Head. A magnetic head having two separate pole pieces in which pole faces of opposite polarity are on opposite sides of the medium. One or both of these pole pieces may be provided with an energizing winding.

Drive Pin. In disk recording, a pin similar to the center pin, but located to one side thereof, which is used to prevent a disk record from slipping on the turntable.

Drive-Pin Hole. In disk recording, a hole in a disk record which accommodates the turntable drive pin.

Dubbing. A term used to describe the combining of two or more sources of sound into a complete recording, at least one of the sources being a recording.

See also: **Re-recording.**

Earphone (Receiver). An electroacoustic transducer intended to be closely coupled acoustically to the ear.

Note—The term "receiver" should be avoided when there is risk of ambiguity.

Earphone Coupler. A cavity of predetermined shape which is used for the testing of earphones. It is provided with a microphone for the measurement of pressures developed in the cavity.

Note 1—Couplers generally have a volume of 6 cubic centimeters for testing regular earphones and a volume of 2 cubic centimeters for testing insert earphones.

Note 2—Specifications for couplers are given in the "Proposed American Standard Method for the Coupler Calibration of Earphones, Z24.9/186."

Eccentric Groove (Eccentric Circle). In disk recording, a locked groove whose center is other than that of the disk record (generally used in connection with mechanical control of phonographs).

Eccentricity. In disk recording, the displacement of the center of the recording groove spiral, with respect to the record center hole.

Echo. A wave which has been reflected or otherwise returned with sufficient magnitude and delay to be perceived in some manner as a wave distinct from that directly transmitted.

Effective Acoustic Center. Of an acoustic generator, the point from which the spherically divergent sound waves, observable at remote points, appear to diverge.

Effective Sound Pressure (Root-Mean-Square Sound Pressure). At a point, the root-mean-square value of the instantaneous sound pressures, over a time interval at the point under consideration. In the case of periodic sound pressures, the interval must be an integral number of periods or an interval long compared to a period. In the case of nonperiodic sound pressures, the interval should be long enough to make the value obtained essentially independent of small changes in the length of the interval.

Note—The term "effective sound pressure" is frequently shortened to "sound pressure."

Electroacoustic Transducer. A transducer for receiving waves from an electric system and delivering waves to an acoustic system, or vice versa.

Electroacoustical Reciprocity Theorem. For an electroacoustic transducer satisfying the reciprocity principle, the quotient of the magnitude of the ratio of the open-circuit voltage at the output terminals (or the short-circuit output current) of the transducer, when used as a sound receiver, to the free-field sound pressure referred to an arbitrarily selected reference point on or near the transducer, divided by the magnitude of the ratio of the sound pressure apparent at a distance d from the reference point to the current flowing at the transducer input terminals (or the voltage applied at the input terminals), when used as a sound emitter, is a constant, called the "reciprocity constant," independent of the type or constructional details of the transducer.

Note—The reciprocity constant is given by

$$\left|\frac{M_o}{S_o}\right| = \left|\frac{M_s}{S_s}\right| = \frac{2d}{pf}\cdot 10^{-7},$$

where

M_o = the open free-field voltage response, as a sound receiver, in open-circuit volts per microbar, referred to the arbitrary reference point on or near the transducer

M_s = the free-field current response in short-circuit amperes per microbar, referred to the arbitrary reference point on or near the transducer
S_o = the sound pressure produced at a distance d centimeters from the arbitrary reference point in microbars per ampere of input current.
S_s = the sound pressure produced at a distance d centimeters from the arbitrary reference point in microbars per volt applied at the input terminals
f = the frequency in cycles per second
p = the density of the medium in grams per cubic centimeter
d = the distance in centimeters from the arbitrary reference point on or near the transducer to the point in which the sound pressure established by the transducer when emitting is evaluated.

Electromechanical Transducer. A transducer for receiving waves from an electric system and delivering waves to a mechanical system, or vice versa.

Electronic Microphone. A microphone which depends for its operation on the generation of a voltage by the motion of one of the electrodes in an electron tube.

Electrophonic Effect. The sensation of hearing produced when an alternating current of suitable frequency and magnitude from an external source is passed through an animal.

Electrostatic Actuator. An apparatus constituting an auxiliary external electrode which permits the application of known electrostatic forces to the diaphragm of a microphone for the purpose of obtaining a primary calibration.

Electrostatic Loudspeaker (Capacitor Loudspeaker) (Condenser Loudspeaker). A loudspeaker in which the mechanical forces are produced by the action of electrostatic fields.

Electrostatic Microphone (Capacitor Microphone) (Condenser Microphone). A microphone which depends for its operation upon variations of its electrostatic capacitance.

Embossing Stylus.[7] A recording stylus with a rounded tip which displaces the material in the recording medium to form a groove.

Equally Tempered Scale. A series of notes selected from a division of the octave (usually) into 12 equal intervals.
See also: **Cent, Table IV.**

Erasing Head. A device for obliterating any previous recordings. It may be used for preconditioning the magnetic media for recording purposes.

Excited Field Loudspeaker. A loudspeaker in which the steady magnetic field is produced by an electromagnet.

Exponential Horn. A horn whose cross-sectional area increases exponentially with axial distance.

Note—If

S = the area of a plane section normal to the axis of the horn at a distance x from the throat of the horn.
S_o = the area of the plane section normal to the axis of the horn at the throat, and
m = a constant which determines the rate of taper or flare of the horn,

then

$$S = S_o e^{mx}.$$

Fast Groove (Fast Spiral). In disk recording, an unmodulated spiral groove having a pitch that is much greater than that of the recorded grooves.

Filler. In mechanical recording, the inert material of a record compound as distinguished from the binder.

Flowed Wax. A mechanical recording medium, in disk form, prepared by melting and flowing wax onto a metal base.

Flutter Echo. A rapid succession of reflected pulses resulting from a single initial pulse.

Force Factor.[2] (a) The force factor of an electromechanical transducer is: (1) the complex quotient of the force required to block the mechanical system divided by the corresponding current in the electric system; (2) the complex quotient of the resulting open-circuit voltage in the electric system divided by the velocity in the mechanical system.

Note 1—Force factors (a(1)) and (a(2)) have the same magnitude when consistent units are used and the transducer satisfies the principle of reciprocity.

Note 2—It is sometimes convenient in an electrostatic or piezoelectric transducer to use the ratios between force and charge or electric displacement, or between voltage and mechanical displacement.

(b) The force factor of an electroacoustic transducer is: (1) the complex quotient of the pressure required to block the acoustic system divided by the corresponding current in the electric system; (2) the complex quotient of the resulting open-circuit voltage in the electric system divided by the volume velocity in the acoustic system.

Note—Force factors (b(1)) and (b(2)) have the same magnitude when consistent units are used and the transducer satisfies the principle of reciprocity.

Free Field. A field (wave or potential) in a homogeneous, isotropic medium free from boundaries. In practice, a field in which the effects of the boundaries are negligible over the region of interest.

Note—The actual pressure impinging on an object (e.g., electroacoustic transducer) placed in an otherwise free sound field will differ from the pressure which would exist at that point with the object removed, unless the acoustic impedance of the object matches the acoustic impedance of the medium.

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[7] Stylus is a term defining a pickup needle or a holder furnished with a jewel or other abrasive-resistant tip. A stylus may or may not be arranged for convenient replacement.

Free-Field Current Response (Receiving Current Sensitivity). Of an electroacoustic transducer used for sound reception, the ratio of the current in the output circuit of the transducer when the output terminals are short-circuited to the free-field sound pressure existing at the transducer location prior to the introduction of the transducer in the sound field. The free-field current response is usually expressed in decibels, viz., 20 times the logarithm to the base 10 of the quotient of the observed ratio divided by the reference ratio, usually 1 ampere per microbar. The free-field response is defined for a plane progressive sound wave whose direction of propagation has a specified orientation with respect to the principal axis of the transducer.

Free-Field Voltage Response (Receiving Voltage Sensitivity). Of an electroacoustic transducer used for sound reception, the ratio of the voltage appearing at the output terminals of the transducer when the output terminals are open-circuited to the free-field sound pressure existing at the transducer location prior to the introduction of the transducer in the sound field. The free-field voltage response is usually expressed in decibels, viz., 20 times the logarithm to the base 10 of the quotient of the observed ratio divided by the reference ratio, usually 1 volt per microbar. The free-field response is defined for a plane progressive sound wave whose direction of propagation has a specified orientation with respect to the principal axis of the transducer.

Free Impedance.[2] Of a transducer, the impedance at the input of the transducer when the impedance of its load is made zero.

Note—The approximation is often made that the free electric impedance of an electroacoustic transducer designed for use in water is that measured with the transducer in air.

Free Motional Impedance.[2] Of a transducer, the complex remainder after the blocked impedance has been subtracted from the free impedance.

Free Progressive Wave (Free Wave). A wave in a medium free from boundary effects. A free wave in a steady state can only be approximated in practice.

Frequency Record. A recording of various known frequencies at known amplitudes, usually for the purpose of testing or measuring.

Frequency-Response Equalization (Equalization). The effect of all frequency discriminative means employed in a transmission system to obtain a desired over-all frequency response.

Fundamental Frequency. Of a periodic quantity, the frequency of a sinusoidal quantity which has the same period as the periodic quantity.

Fundamental Tone. (a) The component in a periodic wave corresponding to the fundamental frequency. (*See* **Fundamental Frequency.**) (b) The component tone of lowest pitch in a complex tone.

Galvanometer Recorder (for Photographic Recording). A combination of mirror and coil suspended in a magnetic field. The application of a signal voltage to the coil causes a reflected light beam from the mirror to pass across a slit in front of a moving photographic film, thus providing a photographic record of the signal.

Gamma. The gamma of a photographic material is the slope of the straight-line portion of the H and D curve. It represents the rate of change of photographic density with the logarithm of exposure. Gamma is a measure of the contrast properties of the film. Both gamma and density specifications are commonly used as controls in the processing of photographic film.

Gap Length. In longitudinal magnetic recording, the gap length is the physical distance between adjacent surfaces of the poles of a magnetic head. (*See* **Magnetic Head.**)

Note—The effective gap length is usually greater than the physical length and can be experimentally determined in some cases.

Gradient Microphone. A microphone the output of which corresponds to a gradient of the sound pressure.

Note—Gradient microphones may be of any order as, for example, zero, first, second, and so forth. A pressure microphone is a gradient microphone of zero order. A velocity microphone is a gradient microphone of order one. Mathematically, from a directivity standpoint for plane waves, the rms response is proportional to $\cos n\theta$, where θ is the angle of incidence, and n is the order of the microphone.

Grain. Of photographic material, a small particle of metallic silver remaining in a photographic emulsion after development and fixing. In the agglomerate, these grains form the dark area of a photographic image.

Graininess. Of a photographic material, the visible coarseness under specified conditions due to silver grains in a developed photographic film.

Groove. In mechanical recording, the track inscribed in the record by the cutting or embossing stylus, including undulations or modulations caused by the vibration of the stylus.

Groove Angle. In disk recording, the angle between the two walls of an unmodulated groove in a radial plane perpendicular to the surface of the recording medium.

Groove Shape. In disk recording, the contour of the groove in a radial plane perpendicular to the surface of the recording medium.

Groove Speed. In disk recording, the linear speed of the groove with respect to the stylus.

Ground Noise. In recording and reproducing, the residual system noise in the absence of the signal. It is usually caused by inhomogeneity in the recording and reproducing media, but may also include amplifier noise such as tube noise or noise generated in resistive elements in the input of the reproducer amplifier system.

Grouping. Nonuniform spacing between the grooves of a disk recording.

Guard Circle. An inner concentric groove inscribed, on disk records, to prevent the pickup from being damaged by being thrown to the center of the record.

***H* and *D* Curve (Hurter and Driffield Curve).** A characteristic curve of a photographic emulsion which is a plot of density against the logarithm of exposure. It is used for the control of photographic processing, and for defining the response characteristics to light of photographic emulsions.

Harmonic. A sinusoidal quantity having a frequency which is an integral multiple of the fundamental frequency of a periodic quantity to which it is related. For example, a wave, the frequency of which is twice the fundamental frequency, is called the second harmonic.

Harmonic Series of Sounds. One in which each basic frequency in the series is an integral multiple of a fundamental frequency.

Hearing Loss (Deafness). The hearing loss of an ear at a specified frequency is the ratio, expressed in decibels, of the threshold of audibility for that ear to the normal threshold.

See also: "Proposed American Standard Specification for Audiometers for General Diagnostic Purposes, Z24.5/158."

Hearing Loss for Speech. The difference in decibels between the speech levels at which the average normal ear and the defective ear respectively reach the same intelligibility, often arbitrarily set at 50 per cent.

Horn Loudspeaker. A loudspeaker in which the radiating element is coupled to the medium by means of a horn.

Horn Mouth. Normally the end of a horn with the larger cross-sectional area.

Horn Throat. Normally the end of a horn with the smaller cross-sectional area.

Hot-Wire Microphone. A microphone which depends for its operation on the change in resistance of a hot wire produced by the cooling or heating effects of a sound wave.

Hydrophone. An electroacoustic transducer which responds to water-borne sound waves and delivers essentially equivalent electric waves.

Note—In a manner similar to the use of the adjective "line" in the definition of line hydrophone **(Line Hydrophone)** and line microphone **(Line Microphone)**, the adjectives "pressure," "velocity," "gradient," "omnidirectional," "unidirectional," "carbon," "capacitor," "crystal," "magnetic," "magnetostriction," "moving-coil," and "moving-conductor," when applied to a hydrophone, have meanings similar to those that apply in the case of a microphone.

See also: **Pressure Microphone,** and so forth.

Induction Loudspeaker. A loudspeaker in which the current which reacts with the steady magnetic field is induced in the moving member.

Infrasonic Frequency (Subsonic Frequency[8]). A frequency lying below the audio-frequency range.

Note—The word "infrasonic" may be used as a modifier to indicate a device or system intended to operate at infrasonic frequencies.

Insert Earphones. Small earphones which fit partially inside the ear.

Instantaneous Recording. A recording which is intended for direct reproduction without further processing.

Instantaneous Sound Pressure. At a point, the total instantaneous pressure at that point minus the static pressure at that point. The commonly used unit is the microbar.

Intensity Level (Specific Sound-Energy Flux Level) (Sound-Energy Flux Density Level). The intensity level, in decibels, of a sound is 10 times the logarithm to the base 10 of the ratio of the intensity of this sound to the reference intensity. The reference intensity shall be stated explicitly.

Note—In discussing sound measurements made with pressure or velocity microphones, especially in enclosures involving normal modes of vibration or in sound fields containing standing waves, caution must be observed in using the terms "intensity" and "intensity level." Under such conditions it is more desirable to use the terms "pressure level" or "velocity level" since the relationship between the intensity and the pressure or velocity is generally unknown.

Interval. The interval between two sounds is their spacing in pitch or frequency, whichever is indicated by the context. The frequency interval is expressed by the ratio of the frequencies or by a logarithm of this ratio.

Just Scale. A musical scale formed by taking three consecutive triads each having the ratio 4:5:6, or 10:12:15 (see Table II).

Note—By consecutive triads is meant triads such that the highest note of one is the lowest note of the other.

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[8] Deprecated.

Lacquer Disks (Cellulose Nitrate Disks). Mechanical recording disks usually made of metal, glass, or paper, and coated with a lacquer compound (often containing cellulose nitrate).

Lacquer Original (Lacquer Master[8]). An original recording on a lacquer surface for the purpose of making a master.

Lacquer Recording. Any recording made on a lacquer recording medium.

Laminated Record. A mechanical recording medium composed of several layers of material. Normally, it is made with a thin face of surface material on each side of a core.

Land. The record surface between two adjacent grooves of a mechanical recording.

Lapel Microphone. A microphone adapted to positioning on the clothing of the user.

Lateral Recording. A mechanical recording in which the groove modulation is perpendicular to the motion of the recording medium and parallel to the surface of the recording medium.

Lead-In Groove (Lead-In Spiral). In disk recording, a blank spiral groove at the beginning of a record generally having a pitch that is much greater than that of the recorded grooves.

Lead-Out Groove (Throw-Out Spiral). In disk recording, a blank spiral groove at the end of a recording generally of a pitch that is much greater than that of the recorded grooves and which is connected to either the locked or eccentric groove.

Lead-Over Groove (Crossover Spiral). In disk recording, a groove cut between recordings of small durations which enables the pickup stylus to travel from one cut to the next.

Level Above Threshold (Sensation Level). Of a sound, the pressure level of the sound in decibels above its threshold of audibility for the individual observer.

Light-Beam Pickup. A phonograph pickup in which a beam of light is a coupling element of the transducer.

Light Modulator. The combination of a source of light, an appropriate optical system, and a means for varying the resulting light beam (such as galvanometer or light valve), so that a sound track may be produced.

Light Valve. A device whose light transmission can be made to vary in accordance with an externally applied electrical quantity, such as voltage, current, electric field, magnetic field, or an electron beam.

Line Hydrophone. A directional hydrophone consisting of a single straight line element, or an array of contiguous or spaced electroacoustic transducing elements disposed on a straight line, or the acoustic equivalent of such an array.

Line Microphone. A directional microphone consisting of a single straight line element, or an array of contiguous or spaced electroacoustic transducing elements, disposed on a straight line, or the acoustic equivalent of such an array.

Lip Microphone. A microphone which is adapted for use in contact with the lip.

Live Room. A room which is characterized by an unusually small amount of sound absorption.

Loaded Impedance. Of a transducer, the impedance at the input of the transducer when the output is connected to its normal load.

Locked Groove (Concentric Groove). In disk recording, a blank and continuous groove at the end of modulated grooves whose function is to prevent further travel of the pickup.

Longitudinal Magnetization. In magnetic recording, magnetization of the recording medium in a direction essentially parallel to the line of travel.

Loudness. The intensive attribute of an auditory sensation in terms of which sound may be ordered on a scale extending from soft to loud.

Note—Loudness depends primarily upon the sound pressure of the stimulus, but it also depends upon the frequency and wave form of the stimulus.

Loudness Contours. Curves which show the related values of sound pressure level and frequency required to produce a given loudness sensation for the typical listener.

Loudness Level. In phons, of a sound, numerically equal to the sound pressure level in decibels, relative to 0.0002 microbar, of a simple tone of frequency 1,000 cycles per second which is judged by the listeners to be equivalent in loudness.

Loudspeaker (Speaker) (Loud Speaker[8]). An electroacoustic transducer usually intended to radiate acoustic power effectively at a distance in air.

Note—The term "speaker" should be avoided when there is risk of ambiguity.

Loudspeaker System. A combination of one or more loudspeakers and all associated baffles, horns, and dividing networks arranged to work together as a coupling means between the driving electric circuit and the acoustic medium.

Loudspeaker Voice Coil. The moving coil of a moving-coil loudspeaker.

Magnetic Armature Loudspeaker (Magnetic Loudspeaker[8]). A loudspeaker comprising a ferromagnetic armature actuated by forces of magnetic attraction.

Magnetic Biasing. The simultaneous conditioning of the magnetic recording medium during recording by superposing an additional magnetic field upon the signal magnetic field.

Note—In general, magnetic biasing is used to obtain a substantially linear relationship between the amplitude of the signal and the remanent flux density in the recording medium.

Magnetic Cutter. A cutter in which the mechanical displacements of the recording stylus are produced by the action of magnetic fields.

Magnetic Head. In magnetic recording, a magnetic head is a transducer for converting electric variations into magnetic variations for storage on magnetic media, for reconverting energy so stored into electric energy or for erasing such stored energy.

Magnetic Plated Wire. A magnetic wire having a core of nonmagnetic material and a plated surface of ferromagnetic material.

Magnetic Powder-Coated Tape (Coated Tape). A tape consisting of a coating of uniformly dispersed, powdered ferromagnetic material on a nonmagnetic base.

Magnetic Powder-Impregnated Tape (Impregnated Tape) (Dispersed Magnetic Powder Tape). A magnetic tape which consists of magnetic particles uniformly dispersed in a nonmagnetic material.

Magnetic Printing (Magnetic Transfer) (Crosstalk[8]). The permanent transfer of a recorded signal from a section of a magnetic recording medium to another section of the same or a different medium when these sections are brought into proximity.

Magnetic Recorder. Equipment incorporating an electromagnetic transducer and means for moving a ferromagnetic recording medium relative to the transducer for recording electric signals as magnetic variations in the medium.

Note—The generic term "magnetic recorder" can also be applied to an instrument which has not only facilities for recording electric signals as magnetic variations, but also for converting such magnetic variations back into electric variations.

Magnetic Recording Head. In magnetic recording, a magnetic head for transforming electric variations into magnetic variations for storage on magnetic media.

Magnetic Recording Medium. A magnetizable material used in a magnetic recorder for retaining the magnetic variations imparted during the recording process. It may have the form of a wire, tape, cylinder, disk, and the like.

Magnetic Recording Reproducer. Equipment for converting magnetic variations on magnetic recording media into electric variations.

Magnetic Reproducing Head. In magnetic recording, a magnetic head for converting magnetic variations on magnetic media into electric variations.

Magnetic Tape. A magnetic recording medium having a width greater than approximately 10 times the thickness. This tape may be homogeneous or coated.

Magnetic Wire. A magnetic recording medium, approximately circular in cross section.

Magnetostriction Loudspeaker. A loudspeaker in which the mechanical displacement is derived from the deformation of a material having magnetostrictive properties.

Magnetostriction Microphone. A microphone which depends for its operation on the generation of an electromotive force by the deformation of a material having magnetostrictive properties.

Mask Microphone. A microphone designed for use inside an oxygen or other type of respiratory mask.

Masking. The amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound. The unit customarily used is the decibel.

Masking Audiogram. A graphical presentation of the masking due to a stated noise. This is plotted, in decibels, as a function of the frequency of the masked tone.

Master. A metal part, normally derived from a disk recording by electroforming, which is a negative of the recording, i.e., a master which has ridges instead of grooves and thus cannot be played with a pointed stylus.

Maximum Sound Pressure. For any given cycle of a periodic wave, the maximum absolute value of the instantaneous sound pressure occurring during that cycle. The commonly used unit is the microbar.

Note—In the case of a sinusoidal sound wave this maximum sound pressure is also called the pressure amplitude.

Mean Free Path. For sound waves in an enclosure, the average distance sound travels between successive reflections in the enclosure.

Mechanical Phonograph Recorder (Mechanical Recorder). An equipment for transforming electric or acoustic signals into mechanical motion of approximately like form and inscribing such motion in an appropriate medium by cutting or embossing.

Mechanical Transmission System. An assembly of elements adapted for the transmission of mechanical power.

Mel. A unit of pitch. By definition, a simple tone of frequency 1,000 cps, 40 db above a listener's threshold, produces a pitch of 1,000 mels. The pitch of any sound that is judged by the listener to be *n* times that of the 1-mel tone is *n* mels.

Microbar, Dyne Per Square Centimeter (Barye[2]) (Bar[2]). A unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

Note—The term "bar" properly denotes a pressure of 10^6 dynes per square centimeter. Unfortunately, in acoustics the bar was used to mean 1 dyne per square centimeter. It is recommended, therefore, in respect to sound pressures that the less ambiguous terms "microbar" or "dyne per square centimeter" be used.

Microphone. An electroacoustic transducer which responds to sound waves and delivers essentially equivalent electric waves.

See also: **Telephone Transmitter.**

Mixer. In a sound transmission, recording, or reproducing system, a device having two or more inputs, usually adjustable, and a common output, which operates to combine linearly in a desired proportion the separate input signals to produce an output signal.

Note—The term is sometimes applied to the operator of the above device.

Modulation Noise (Noise Behind the Signal). The noise caused by the signal. The signal is not to be included as part of the noise.

Note—The term is used where the noise level is a function of the strength of the signal.

Mold. In disk recording, a mold is a metal part derived from a master by electroforming which is a positive of the recording, i.e., it has grooves similar to a recording and thus can be played in a manner similar to a record.

Motional Impedance[2] (Loaded Motional Impedance). Of a transducer, the complex remainder after the blocked impedance has been subtracted from the loaded impedance.

Moving-Coil Loudspeaker (Dynamic Loudspeaker). A moving-conductor loudspeaker in which the moving conductor is in the form of a coil conductively connected to the source of electric energy.

Moving-Coil Microphone (Dynamic Microphone). A moving-conductor microphone in which the movable conductor is in the form of a coil.

Moving-Coil Pickup (Dynamic Reproducer). A phonograph pickup, the electric output of which results from the motion of a conductor or coil in a magnetic field.

Moving-Conductor Loudspeaker. A loudspeaker in which the mechanical forces result from magnetic reactions between the field of the current in a moving conductor and a steady magnetic field.

Moving-Conductor Microphone. A microphone the electric output of which results from the motion of a conductor in a magnetic field.

Multicellular Horn. A cluster of horns with juxtaposed mouths which lie in a common surface. The purpose of the cluster is to control the directional pattern of the radiated energy.

Multiple Sound Track. Consists of a group of sound tracks, printed adjacently on a common base, independent in character but in a common time relationship, e.g., two or more have been used for stereophonic sound recording.

Multitrack Recording System. A recording system which provides two or more recording paths on a medium, which may carry either related or unrelated recordings in common time relationship.

Musical Echo. A flutter echo that is periodic and has a flutter the frequency of which is in the audible range.

No. 1 Mold (Mother) (Metal Positive). A mold derived by electroforming from the original master.

No. 2, No. 3, etc. Master. A master produced by electroforming from a No. 1, No. 2, etc. mold.

No. 2 No. 3 etc. Mold. A mold derived by electroforming from a No. 2, No. 3, etc. master.

Noise Reduction. In photographic recording and reproducing, a process whereby the average transmission of the sound track of the print (averaged across the track) is decreased for signals of low level and increased for signals of high level.

Note 1—Since the ground noise introduced by the sound track is less at low transmission, this process reduces film noise during soft passages. The effect is normally accomplished automatically.

Note. A conventional sign used to indicate the pitch, or the duration, or both, of a tone sensation. It is also the sensation itself or the vibration causing the sensation. The word serves when no distinction is desired between the symbol, the sensation, and the physical stimulus.

Octave. The interval between two sounds having a basic frequency ratio of two. By extension, the octave is the interval between any two frequencies having the ratio 2:1.

Note—The interval, in octaves, between any two frequencies is the logarithm to the base two (or 3.322 times the logarithm to the base 10) of the frequency ratio.

Octave-Band Pressure Level (Octave Pressure Level). Of a sound, the band pressure level for a frequency band corresponding to a specified octave.

Note—The location of an octave-band pressure level on a frequency scale is usually specified as the geometric mean of the upper and lower frequencies of the octave.

Offset Angle. In lateral disk reproduction, the offset angle is the smaller of the two angles between the projections into the plane of the disk of the vibration axis of the pickup stylus and the line connecting the vertical pivot (assuming a horizontal disk) of the pickup arm with the stylus point.

Omnidirectional Microphone (Nondirectional Microphone). A microphone the response of which is essentially independent of the direction of sound incidence.

Note—It should be noted that, in this case, omnidirectional refers to elevation as well as azimuth. In radio antenna practice this is not necessarily the case.

Opacity. Of an optical path, the reciprocal of transmission.

See also: **Transmission (Transmittance)**

Optical Pattern (Christmas Tree Pattern). In mechanical recording, a pattern which is observed when the surface of a record is illuminated by a light beam of essentially parallel rays.

Original Master (Metal Master) (Metal Negative) (No. 1 Master). In disk recording, the master produced by electroforming from the face of a wax or lacquer recording.

Overcutting. In disk recording, the effect of excessive level characterized by one groove cutting through into an adjacent one.

Overtone. (a) A physical component of a complex sound having a frequency higher than that of the basic frequency. (b) A component of a complex tone having a pitch higher than that of the fundamental pitch.

Note—The term "overtone" has frequently been used in place of "harmonic," the nth harmonic being called the $(n-1)$st overtone. There is, however, ambiguity sometimes in the numbering of components of a complex sound when the word overtone is employed. Moreover, the word "tone" has many different meanings so that it is preferable to employ terms which do not involve "tone" wherever possible.

See also: **Partial**

PM Erasing Head. One which uses the fields of one or more permanent magnets for erasing.

Parabolic-Reflector Microphone. A microphone employing a parabolic reflector to improve its directivity and sensitivity.

Partial. (a) A physical component of a complex tone. (b) A component of a sound sensation which may be distinguished as a simple tone that cannot be further analyzed by the ear and which contributes to the character of the complex sound.

Note 1—The frequency of a partial may be either higher or lower than the basic frequency and may or may not be an integral multiple or submultiple of the basic frequency. (For definition of basic frequency, *see* **Basic Frequency.**) If the frequency is not a multiple or submultiple, the partial is inharmonic.

Note 2—When a system is maintained in steady forced vibration at a basic frequency equal to one of the frequencies of the normal modes of vibration of the system, the partials in the resulting complex tone are not necessarily identical in frequency with those of the other normal modes of vibration.

Particle Velocity. In a sound wave, the velocity of a given infinitesimal part of the medium, with reference to the medium as a whole, due to the sound wave. The commonly used unit is the centimeter per second.

Note—The terms "instantaneous particle velocity," "effective particle velocity," "maximum particle velocity," and "peak particle velocity" have meanings which correspond with those of the related terms used for sound pressure.

Peak Sound Pressure. For any specified time interval, the maximum absolute value of the instantaneous sound pressure in that interval. The commonly used unit is the microbar.

Note—In the case of a periodic wave, if the time interval considered is a complete period, the peak sound pressure becomes identical with the maximum sound pressure.

Permanent Magnet Loudspeaker. A moving-conductor loudspeaker in which the steady field is produced by means of a permanent magnet.

Per Cent Hearing. At any given frequency, 100 minus the per cent hearing loss at that frequency.

Per Cent Hearing Loss (Per Cent Deafness). At a given frequency, 100 times the ratio of the hearing loss in decibels to the number of decibels between the normal threshold levels of audibility and feeling.

Note 1—A weighted mean of the per cent hearing losses at specified frequencies is often used as a single measure of the loss of hearing.

Note 2—The American Medical Association has defined percentage loss of hearing for medicolegal use. (See the *Journal of the American Medical Association*, vol. 133, pp. 396–397; February 8, 1947.)

Perpendicular Magnetization. In magnetic recording, magnetization of the recording medium in a direction perpendicular to the line of travel, and parallel to the smallest cross-sectional dimension of the medium.

Note—In this type of magnetization, either single pole-piece or double pole-piece magnetic heads may be used.

Phase-Shift Microphone. A microphone employing phase-shift networks to produce directional properties.

Phon. The unit of loudness level as specified in definition **Loudness Level.**

Phonograph Pickup (Mechanical Reproducer). A mechanoelectric transducer which is actuated by modulations present in the groove of the recording medium and which transforms this mechanical input into an electric output.

Note—Where no confusion will result, the term "phonograph pickup" may be shortened to "pickup."

Photographic Emulsion. The light-sensitive coating on photographic film consisting usually of a gelatin containing silver halide.

Photographic Sound Recorder (Optical Sound Recorder). Equipment incorporating means for producing a modulated light beam and means for moving a light-sensitive medium relative to the beam for recording signals derived from sound signals.

Photographic Sound Reproducer (Optical Sound Reproducer). A combination of light source, optical system, photoelectric cell, or other light-sensitive device such as a photoconductive cell, and a mechanism for moving a medium carrying an optical sound record (usually film), by means of which the recorded variations may be converted into electric signals of approximately like form.

Photographic Transmission Density[9] (Optical Density). The common logarithm of opacity. Hence, film transmitting 100 per cent of the light has a density of zero, transmitting 10 per cent a density of 1, and so forth. Density may be diffuse, specular, or intermediate. Conditions must be specified.

Pickup Arm (Tone Arm). A pivoted arm arranged to hold a pickup.

Pickup Cartridge. The removable portion of a pickup containing the electromechanical translating elements and the reproducing stylus.

Pinch Effect. In disk recording, the pinch effect is a pinching of the reproducing stylus tip twice each cycle in the reproduction of lateral recordings due to a decrease of the groove angle cut by the recording stylus when it is moving across the record as it swings from a negative to a positive peak.

Pistonphone. A small chamber equipped with a reciprocating piston of measurable displacement which permits the establishment of a known sound pressure in the chamber.

Pitch. That attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high, such as a musical scale.

Note 1—Pitch depends primarily upon the frequency of the sound stimulus, but it also depends upon the sound pressure and wave form of the stimulus.

Note 2—The pitch of a sound may be described by the frequency of that simple tone, having a specified sound pressure or loudness level, which seems to the average normal ear to produce the same pitch.

Playback. An expression used to denote reproduction of a recording.

Pneumatic Loudspeaker. A loudspeaker in which the acoustical output results from controlled variation of an air stream.

Poid. The curve traced by the center of a sphere when it rolls or slides over a surface having a sinusoidal profile.

Pre-emphasis (Pre-equalization). In recording, pre-emphasis is an arbitrary change in the frequency response of a recording system from its basic response (such as constant velocity or amplitude) for the purpose of improvement in signal-to-noise ratio, or the reduction of distortion.

Preform (Biscuit[8]). In disk recording, a preform is a small slab of record stock material as it is prepared for use in the record presses.

Pressing. In disk recording, a pressing is a record produced in a record-molding press from a master or stamper.

Pressure Microphone. A microphone in which the electric output substantially corresponds to the instantaneous sound pressure of the impressed sound waves.

Note—A pressure microphone is a gradient microphone (*see* **Gradient Microphone**) of zero order and is nondirectional when its dimensions are small compared to a wavelength.

Pressure Spectrum Level. Of a sound at a specified frequency, the effective sound pressure level for the sound energy contained within a band 1 cycle per second wide, centered at the specified frequency. Ordinarily this has significance only for sound having a continuous distribution of energy within the frequency range under consideration. The reference pressure shall be explicitly stated. (*See* **Sound Pressure Level.**)

Note—Since, in practice, it is necessary to employ filters having an effective bandwidth greater than 1 cycle per second, the pressure spectrum level is, in general, a computed quantity. For a sound having a uniform distribution of energy, the computation can be made as follows: Let L_{ps} be the desired pressure spectrum level, p be the effective pressure measured through the filter system, p_o be reference sound pressure, Δf be the effective bandwidth of the filter system, and $\Delta_0 f$ be the reference bandwidth (1 cycle per second), then

$$L_{ps} = 10 \log_{10} \left[\frac{p^2/\Delta f}{p_0{}^2/\Delta_0 f} \right].$$

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[9] For details of measurement and specifications, see "American Standard Diffuse Transmission Density, Z38.2.5—1946," or the latest edition thereof approved by the American Standards Association.

For computational purposes, if L_p is the band pressure level observed through the filter, the above relation reduces to

$$L_{ps} = L_p - 10 \log_{10} \frac{\Delta f}{\Delta_0 f}.$$

Principal Axis. Of a transducer used for sound emission or reception, a reference direction for angular co-ordinates used in describing the directional characteristics of the transducer. It is usually an axis of structural symmetry, or the direction of maximum response; but if these do not coincide, the reference direction must be described explicitly.

Push-Pull Microphone. A microphone which makes use of two like microphone elements actuated by the same sound waves and operating 180° out of phase.

Pythagorean Scale. A musical scale such that the frequency intervals are represented by the ratios of integral powers of the numbers 2 and 3.

Rate of Decay. The time rate at which the sound pressure level (or velocity level, or sound-energy density level) is decreasing at a given point and at a given time. The practical unit is the decibel per second.

Rayleigh Disk. A special form of acoustic radiometer which is used for the fundamental measurement of particle velocity.

Recording Channel. The term refers to one of a number of independent recorders in a recording system or to independent recording tracks on a recording medium.

Note—One or more channels may be used at the same time for covering different ranges of the transmitted frequency band, for multichannel recording, or for control purposes.

Recording Loss. In mechanical recording, the loss in recorded level whereby the amplitude of the wave in the recording medium differs from the amplitude executed by the recording stylus.

Recording Stylus.[10] A tool which inscribes the groove into the recording medium.

Reflex Baffle. A loudspeaker baffle in which a portion of the radiation from the rear of the diaphragm is propagated forward after controlled shift of phase or other modification, the purpose being to increase the over-all radiation in some portion of the frequency spectrum.

Refraction Loss. That part of the transmission loss due to refraction resulting from nonuniformity of the medium.

Relative Response. The ratio, usually expressed in decibels, of the response under some particular conditions to the response under reference conditions, which should be stated explicitly.

Relative Velocity. Of a point with respect to a reference frame, the time rate of change of a position vector of that point with respect to the reference frame.

Reproducing Stylus.[10] A mechanical element adapted to following the modulations of a record groove and transmitting the mechanical motion thus derived to the pick-up mechanism.

Re-recording. The process of making a recording by reproducing a recorded sound source and recording this reproduction.

See also: **Dubbing.**

Re-recording System. An association of reproducers, mixers, amplifiers, and recorders capable of being used for combining or modifying various sound recordings to provide a final sound record. Recording of speech, music, and sound effects may be so combined.

Reverberation. The persistence of sound at a given point, after direct reception from the source has stopped.

Note—This may be due (a) (as in the case of rooms) to repeated reflections from a small number of boundaries or to the free decay of the normal modes of vibration that were excited by the sound source; (b) (as in the case of underwater sound in the ocean) to scattering from a large number of inhomogeneities in the medium or reflection from bounding surfaces.

Reverberation Chamber. An enclosure in which all of the surfaces have been made as sound-reflective as possible. Reverberation chambers are used for certain acoustic measurements.

Reverberation Time. For a given frequency, the time required for the average sound-energy density, originally in a steady state, to decrease after the source is stopped to one-millionth of its initial value (60 db).

Note—Usually the pressure level for the upper part of this range is measured and the result extrapolated to cover 60 db.

Reverberation Time Meter. An instrument for measuring the reverberation time of an enclosure.

Ribbon Microphone. A moving-conductor microphone in which the moving conductor is in the form of a ribbon which is directly driven by the sound waves.

Ring Head. A magnetic head in which the magnetic material forms an enclosure with one or more air gaps. The magnetic recording medium bridges one of these gaps and is in contact with or in close proximity to the pole pieces on one side only.

Rumble (Turntable Rumble). Low-frequency vibration mechanically transmitted to the recording or reproducing turntable and superimposed on the reproduction.

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[10] Stylus is a term defining a pickup needle or a holder furnished with a jewel or other abrasive-resistant tip. A stylus may or may not be arranged for convenient replacement.

Sabin (Square-Foot Unit of Absorption). A measure of the sound absorption of a surface. It is the equivalent of 1 square foot of a perfectly absorptive surface.

Scale. A musical scale is a series of notes (symbols, sensations, or stimuli) arranged from low to high by a specified scheme of intervals, suitable for musical purposes.

Scattering Loss. That part of the transmission loss which is due to scattering within the medium or due to roughness of the reflecting surface.

Scoring System. For motion picture production, a recording system used for recording music to be reproduced in timed relationship with a motion picture.

Semitone (Half-Step). The interval between two sounds whose basic frequency ratio is approximately equal to the twelfth root of two.

Note—The interval, in equally tempered semitones, between any two frequencies, is 12 times the logarithm to the base 2 (or 39.86 times the logarithm to the base 10) of the frequency ratio.

Sensitometry. The measurement of the light response characteristics of photographic film under specified conditions of exposure and development.

Shading. A method of controlling the directivity pattern of a transducer through control of the distribution of phase and amplitude of the transducer action over the active face.

Shaving. In mechanical recording, the process of removing material from the surface of a recording medium for the purpose of obtaining a new recording surface.

Shear Wave (Rotation Wave). A wave in an elastic medium which causes an element of the medium to change its shape without a change of volume.

Note 1—Mathematically, a wave whose velocity field has zero divergence.

Note 2—A shear plane wave in an isotropic medium is a transverse wave.

Shock Motion. In a mechanical system, transient motion which is characterized by suddenness and by significant relative displacements.

Side Thrust. In disk recording, the radial component of force on a pickup arm caused by the stylus drag.

Simple Sound Source. A source which radiates sound uniformly in all directions under free-field conditions.

Simple Tone (Pure Tone). (a) A sound wave, the instantaneous sound pressure of which is a simple sinusoidal function of the time. (b) A sound sensation characterized by its singleness of pitch.

Single Pole-Piece Magnetic Head. A magnetic head having a single pole piece on one side of the recording medium.

Single Track (Standard Track). A variable-density or variable-area sound track in which both positive and negative halves of the signal are linearly recorded.

Sone. A unit of loudness. By definition, a simple tone of frequency 1,000 cps, 40 db above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be *n* times that of the 1-sone tone is *n* sones.

Note 1—A millisone is equal to 0.001 sone.

Note 2—The loudness scale is a relation between loudness and level above threshold [*see* **Level Above Threshold (Sensation Level)**] for a particular listener. In presenting data relating loudness in sones to sound pressure level, or in averaging the loudness scales of several listeners, the thresholds (measured or assumed) should be specified.

Note 3—The term "loudness unit" has been used for the basic subdivision of a loudness scale based on group judgment on which a loudness level of 40 phons has a loudness of approximately 1,000 loudness units. For example, see Fig. 1 of "American Standard for Noise Measurement, Z24.2—1942."

Sound. (a) An alteration in pressure, stress, particle displacement, particle velocity, and so forth, which is propagated in an elastic material, or the superposition of such propagated alterations. (b) Also, auditory sensation which is usually evoked by the alterations described above.

Note—In case of possible confusion, the terms "sound wave" or "elastic wave" may be used for concept (a), and the term "sound sensation" for concept (b).

Sound Absorption. The process by which sound energy is diminished in passing through a medium or in striking a surface.

Sound Absorption Coefficient (Acoustical Absorptivity). The fraction of incident sound energy absorbed by the surface or medium.

Note 1—The surface is considered part of an infinite area.

Note 2—The value of the coefficient is a function of the angle of incidence of the sound.

Sound Analyzer. A device for measuring the band pressure level or pressure spectrum level of a sound as a function of frequency.

Sound Articulation (Per Cent Sound Articulation).[6] The per cent articulation obtained when the speech units considered are fundamental sounds (usually combined into meaningless syllables).

Sound Energy. Of a given part of a medium, the total energy in this part of the medium minus the energy which would exist in the same part of the medium with no sound waves present.

Sound-Energy Density. At a point, in a sound field, the sound energy contained in a given infinitesimal part of the medium divided by the volume of that part of the medium. The commonly used unit is the erg per cubic centimeter.

Note 1—The terms "instantaneous energy density," "maximum energy density," and "peak energy density" have meanings analogous to the related terms used for sound pressure.

Note 2—In speaking of average energy density in general, it is necessary to distinguish between the space average (at a given instant) and the time average (at a given point).

Sound Energy Flux. The average rate of flow of sound energy for one period through any specified area. The commonly used unit is the erg per second. Expressed mathematically, the sound-energy flux J is

$$J = \frac{1}{T}\int_0^T pSv_a dt$$

where

T = an integral number of periods or a time long compared to a period

p = the instantaneous sound pressure over the area S

v_a = the component of the instantaneous particle velocity in the direction a, normal to the area S.

Note—In a medium of density ρ, for a plane or spherical free wave having a velocity of propagation c, the sound-energy flux through the area S, corresponding to an effective sound pressure p, is

$$J = \frac{p^2 S}{\rho c} \cos \theta$$

where

θ = the angle between the direction of propagation of the sound and the normal to the area S.

Sound Field. A region containing sound waves.

Sound Intensity[11] **(Specific Sound-Energy Flux) (Sound-Energy Flux Density).** In a specified direction at a point, the average rate of sound energy transmitted in the specified direction through a unit area normal to this direction at the point considered. The commonly used unit is the erg per second per square centimeter, but sound intensity may also be expressed in watts per square centimeter.

Note 1—The sound intensity in any specified direction a of a sound field is the sound-energy flux through a unit area normal to that direction. This is given by the expression

$$I_a = \frac{1}{T}\int_0^T pv_a dt$$

where

T = an integral number of periods or a time long compared to a period

p = the instantaneous sound pressure

v_a = the component of the instantaneous particle velocity in the direction a.

Note 2—In the case of a free plane or spherical wave having the effective sound pressure p, the velocity of propagation c, in a medium of density ρ, the intensity in the direction of propagation is given by

$$I = \frac{p^2}{\rho c}.$$

Sound Level. At a point in a sound field, the weighted sound pressure level determined in the manner specified in the latest edition of "American Standard Sound Level Meters for Measurement of Noise and Other Sounds."

Note 1—The current edition of this standard is Z24.3—1944.

Note 2—The meter reading (in decibels) corresponds to a value of the sound pressure integrated over the audible frequency range with a specified frequency weighting and integration time.

See also: **Sound Level Meter.**

Sound Level Meter. An instrument including a microphone, an amplifier, an output meter, and frequency weighting networks for the measurement of noise and sound levels in a specified manner; the measurements are intended to approximate the loudness level which would be obtained by the more elaborate ear balance method.

Note—Specifications for sound-level meters for measurement of noise and other sounds are given in "American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3—1944."

Sound Power of a Source. The total sound energy radiated by the source per unit of time. The commonly used unit is the erg per second but the power may also be expressed in watts.

Sound Pressure Level.[11] In decibels, of a sound, 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated.

Note 1—The following reference pressures are in common use:

(a) 2×10^{-4} microbar
(b) 1 microbar

Reference pressure (a) has been in general use for measurements dealing with hearing and sound level measurements in air and liquids, while (b) has gained widespread use for calibrations and many types of sound level measurements in liquids.

Note 2—It is to be noted that in many sound fields the sound pressure ratios are not proportional to the square root of corresponding power ratios and hence cannot be expressed in decibels in the strict sense; however, it is common practice to extend the use of the decibel to these cases.

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[11] See note under **Intensity Level.**

Sound Probe. A device for exploring a sound field without significantly disturbing the field in the region being explored.

Note—A sound probe may take the form of a small microphone or a small tubular attachment added to a conventional microphone.

Sound Recording System. A combination of transducing devices and associated equipment suitable for storing sound in a form capable of subsequent reproduction.

Sound Reflection Coefficient (Acoustical Reflectivity). The sound reflection coefficient of a surface not a generator is the ratio of the rate of flow of sound energy reflected from the surface, on the side of incidence, to the incident rate of flow. Unless otherwise specified, all possible directions of incident flow are assumed to be equally probable. Also, unless otherwise stated, the values given apply to a portion of an infinite surface, thus eliminating edge effects.

Sound Reproducing System. A combination of transducing devices and associated equipment for reproducing recorded sound.

Sound Track. A narrow band, usually along the margin of a sound film, which carries the sound record. In some cases, a plurality of such bands may be used.

Sound Transmission Coefficient (Acoustical Transmittivity). Of an interface or septum, the ratio of the transmitted to incident sound energy. The value of the coefficient is a function of the angle of incidence of the sound.

Specific Acoustic Impedance[2] **(Unit Area Acoustic Impedance).** At a point in the medium, the complex ratio of sound pressure to particle velocity.

Specific Acoustic Reactance.[2] The imaginary component of the specific acoustic impedance.

Specific Acoustic Resistance.[2] The real component of the specific acoustic impedance.

Split Hydrophone. A directional hydrophone in which electroacoustic transducing elements are so divided and arranged that each division may induce a separate electromotive force between its own electric terminals.

Split Projector. A directional projector in which electroacoustic transducing elements are so divided and arranged that each division may be energized separately through its own electric terminals.

Sputtering (Cathode Sputtering). A process sometimes used in the production of the metal master wherein the original is coated with an electric conducting layer by means of an electric discharge in a vacuum.

Note—This is done prior to electroplating a heavier deposit.

Squeeze Track. A variable density sound track wherein, by means of adjustable masking of the recording light beam and simultaneous increase of the electric signal applied to the light modulator, a track having variable width with greater signal-to-noise ratio is obtained.

Stamper. A negative (generally made of metal by electroforming) from which finished pressings are molded.

Standard Microphone. A microphone the response of which is accurately known for the condition under which it is to be used.

Standard Pitch. The standard pitch is based on the tone "A" of 440 cycles per second.

Note 1—With this standard the frequency of Middle C is 261.6 cycles per second (See Table V).

Note 2—Musical instruments are to be capable of complying with this standard when played where the ambient temperature is 22°C (72°F).

TABLE V

FREQUENCIES OF THE TONES OF THE USUAL EQUALLY TEMPERED SCALE, ARRANGED BY CORRESPONDING PIANO KEY NUMBERS, AND BASED ON THE A OF 440 CYCLES PER SECOND

Note Name	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Key No.*	*Freq. cps*	*Note Name*
A	1	27.500	13	55.000	25	110.000	37	220.000	49	440.000	61	880.000	73	1,760.000	85	3,520.000	A
A♯—B♭	2	29.135	14	58.270	26	116.541	38	233.072	50	466.164	62	932.328	74	1,864.655	86	3,729.310	A♯—B♭
B	3	30.868	15	61.735	27	123.471	39	246.942	51	493.883	63	987.767	75	1,975.533	87	3,951.066	B
C	4	32.703	16	65.406	28	130.813	40	261.626	52	523.251	64	1,046.502	76	2,093.005	88	4,186.009	C
C♯—D♭	5	34.648	17	69.296	29	138.591	41	277.183	53	554.365	65	1,108.731	77	2,217.461			C♯—D♭
D	6	36.708	18	73.416	30	146.832	42	293.665	54	587.330	66	1,174.659	78	2,349.318			D
D♯—E♭	7	38.891	19	77.782	31	155.563	43	311.127	55	622.254	67	1,244.508	79	2,489.016			D♯—E♭
E	8	41.203	20	82.407	32	164.814	44	329.628	56	659.255	68	1,318.510	80	2,637.021			E
F	9	43.654	21	87.307	33	174.614	45	349.228	57	698.456	69	1,396.913	81	2,793.826			F
F♯—G♭	10	46.249	22	92.499	34	184.997	46	369.994	58	739.989	70	1,479.978	82	2,959.955			F♯—G♭
G	11	48.999	23	97.999	35	195.998	47	391.995	59	783.991	71	1,567.982	83	3,135.964			G
G♯—A♭	12	51.913	24	103.826	36	207.652	48	415.305	60	830.609	72	1,661.219	84	3,322.438			G♯—A♭

Standard Sea Water Conditions. Those of sea water at a static pressure of 1 atmosphere, a temperature of 15°C, and a salinity such that the velocity of propagation is exactly 1,500 meters per second.

Note—Under these conditions, the following other properties are derived from experimental data:

Salinity[12] $S=31.60$ parts per thousand
Density[13] $\rho=1.02338$ grams per cubic centimeter
Characteristic acoustic impedance, $\rho c=1.53507\times10^2$ cgs units
Pressure spectrum level of thermal noise[14] $10\log_{10}(kT\rho c)=82.17$ db below 1 microbar.

This Standard is adopted for the purpose of establishing consistent relationships between acoustical quantities which involve the properties of the sound medium. It is not intended for calibration of echo range or depth scales.

The standard values have been chosen to represent closely the average conditions on continental shelves except in tropical waters. The values likely to be encountered under actual conditions will usually lie between the limits given in Table VI.

Hydrostatic pressure increases the velocity by 0.018 meter per second per meter of depth. It also increases the density by approximately 0.000045 gram per cm³ per meter of depth.

Static Pressure (Hydrostatic Pressure). At a point in a medium, the pressure that would exist at that point with no sound waves present. In acoustics, the commonly used unit is the microbar.

Steady-State Oscillation (Steady-State Vibration). Steady-state oscillation exists in a system if the motion at each point is a periodic quantity.

Note—This is frequently a special case of forced oscillation.

Stereophonic Sound System. A sound system in which a plurality of microphones, transmission channels, and loudspeakers is arranged so as to provide a sensation of spatial distribution of the sound sources to the listener to the reproduction.

Streaming. The production of unidirectional flow currents in a medium, arising from the presence of sound waves.

Strength of a Sound Source (Strength of a Simple Source). The maximum instantaneous rate of volume displacement produced by the source when emitting a wave with sinusoidal time variation.

Striation Technique. A method for rendering sound waves visible by using their individual ability to refract light waves.

Stylus Drag (Needle Drag). An expression used to denote the force resulting from friction between the surface of the recording medium and the reproducing stylus.

Stylus Force. The vertical force exerted on a stationary recording medium by the stylus when in its operating position.

Supersonics. The general subject covering phenomena associated with speed higher than the speed of sound (as in case of aircraft and projectiles traveling faster than sound).

Note—This term has been used in acoustics synonymously with "ultrasonics." Such usage is now deprecated.

Surface Noise. In mechanical recording, the noise component in the electric output of a pickup due to irregularities in the contact surface of the groove.

See also: **Ground Noise.**

Syllable Articulation (Per Cent Syllable Articulation).[6] The per cent articulation obtained when the speech units considered are syllables (usually meaningless and usually of the consonant-vowel-consonant type).

Telephone Receiver. An earphone for use in a telephone system.

See also: **Earphone (Receiver).**

TABLE VI
REPRESENTATIVE WATER CONDITIONS

	Fresh Water		*Sea Water*			
Salinity (parts per 1,000)	0		30		36	
Temperature (degrees centigrade)	4	25	5	20	15	25
Velocity (meters per second)	1,418.3	1,493.2	1,461.0	1,513.2	1,505.0	1,523.8
Density (grams per cm³)	1.00000	0.99707	1.02375	1.02099	1.02677	1.02412
Characteristic Impedance×10⁻⁵ (cgs units)	1.4183	1.4888	1.4957	1.5450	1.5453	1.5698

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[12] S. Kuwahara, "Velocity of sound in sea-water and calculation of the velocity for use in sonic sounding," *Hydrographic Review*, vol. 16, pp. 123–140; 1939.

[13] Martin Knudsen, "Hydrographical Tables," Copenhagen, Denmark; 1901, 1931.

[14] "Smithsonian Physical Tables," 8th ed.; 1934.

Telephone Transmitter. A microphone for use in a telephone system.

See also: **Microphone.**

Thermophone. An electroacoustic transducer in which sound waves of calculable magnitude result from the expansion and contraction of the air adjacent to a conductor whose temperature varies in response to a current input.

Note—When used for the calibration of pressure microphones, a thermophone is generally used in a cavity the dimensions of which are small compared to a wavelength.

Threshold of Audibility (Threshold of Detectability). For a specified signal, the minimum effective sound pressure of the signal that is capable of evoking an auditory sensation in a specified fraction of the trials. The characteristics of the signal, the manner in which it is presented to the listener, and the point at which the sound pressure is measured must be specified.

Note 1—Unless otherwise indicated, the ambient noise reaching the ears is assumed to be negligible.

Note 2—The threshold may be expressed in decibels relative to 0.0002 microbar or to 1 microbar.

Note 3—Instead of the method of constant stimuli, which is implied by the phrase "in a specified fraction of the trials," another psychophysical method (which should be specified) may be employed.

Threshold of Feeling (or Discomfort, Tickle, or Pain). For a specified signal, the minimum effective sound pressure of that signal which in a specified fraction of the trials will stimulate the ear to a point at which there is the sensation of feeling (or discomfort, tickle, or pain).

Note 1—Characteristics of the signal and the measuring technique must be specified in every case.

Note 2—This threshold is customarily expressed in decibels relative to 0.0002 microbar or to 1 microbar.

Throat Microphone. A microphone normally actuated by mechanical contact with the throat.

Timbre (Musical Quality). That attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar.

Note—Timbre depends primarily upon the spectrum of the stimulus, but it also depends upon the wave form, the sound pressure, and the frequency location of the spectrum of the stimulus.

Toe and Shoulder (of an *H* and *D* Curve). The terms applied to the nonlinear portions of the *H* and *D* curve which lie, respectively, below and above the straight portion of this curve.

Tone. (a) A sound wave capable of exciting an auditory sensation having pitch. (b) A sound sensation having pitch.

Tracing Distortion. The nonlinear distortion introduced in the reproduction of mechanical recording because the curve traced by the motion of the reproducing stylus is not an exact replica of the modulated groove. For example, in the case of a sine-wave modulation in vertical recording the curve traced by the center of the tip of a stylus is a poid.

Tracking Error. In lateral mechanical recording, the angle between the vibration axis of the mechanical system of the pickup and a plane containing the tangent to the unmodulated record groove which is perpendicular to the surface of the recording medium at the point of needle contact.

Transducer Equivalent Noise Pressure (Equivalent Noise Pressure). Of an electroacoustic transducer or system used for sound reception, the root-mean-square sound pressure of a sinusoidal plane progressive wave which, if propagated parallel to the principal axis of the transducer, would produce an open-circuit signal voltage equal to the root-mean-square of the inherent open-circuit noise voltage of the transducer in a transmission band having a bandwidth of 1 cycle per second and centered on the frequency of the plane sound wave.

Note—If the equivalent noise pressure of the transducer is a function of secondary variables, such as ambient temperature or pressure, the applicable value of these quantities should be stated explicitly.

Transient Motion. Any motion which has not reached or has ceased to be a steady state.

Transition Frequency (Crossover Frequency). Of a disk recording system, the frequency corresponding to the point of intersection of the asymptotes to the constant amplitude and the constant velocity portions of its frequency response curve. This curve is plotted with output voltage ratio in decibels as the ordinate and the logarithm of the frequency as the abscissa.

Translation Loss (Playback Loss). The loss in the reproduction of a mechanical recording whereby the amplitude of motion of the reproducing stylus differs from the recorded amplitude in the medium.

Transmission (Transmittance). Transmission, as applied to photographic recording, is the ratio of the light flux transmitted by the medium to the light flux incident upon it. Transmission may be either diffuse or specular.

Transmitting Current Response. Of an electroacoustic transducer used for sound emission, the ratio of the sound pressure apparent at a distance of 1 meter in a specified direction from the effective acoustic center of the transducer to the current flowing at the electric input terminals. The transmitting current response is usually expressed in decibels above a reference current response of 1 microbar per ampere.

Note—The sound pressure apparent at a distance of 1 meter is determined by multiplying the sound pressure observed at a remote point where the sound field is spherically divergent by the ratio of the distance of that point, in meters, from the effective acoustic center of the projector, to the reference distance of 1 meter.

Transmitting Efficiency (Projector Efficiency). Of an electroacoustic transducer, the ratio of the total acoustic power output to the electric power input. In computing the electric power input, it is customary to omit any electric power supplied for polarization or bias.

Transmitting Power Response (Projector Power Response). Of an electroacoustic transducer used for sound emission, the ratio of the mean-square sound pressure apparent at a distance of 1 meter in a specified direction from the effective acoustic center of the transducer to the electric power input. The transmitting power response is usually expressed in decibels above a reference response of 1 microbar squared per watt of electric power input.

Note—The sound pressure apparent at a distance of 1 meter is determined by multiplying the sound pressure observed at a remote point where the sound field is spherically divergent by the ratio of the distance of that point, in meters, from the effective acoustic center of the projector, to the reference distance of 1 meter.

Transmitting Voltage Response. Of an electroacoustic transducer used for sound emission, the ratio of the sound pressure apparent at a distance of 1 meter in a specified direction from the effective acoustic center of the transducer to the signal voltage applied at the electric input terminals. The transmitting voltage response is usually expressed in decibels above a reference voltage response of 1 microbar per volt.

Note—The sound pressure apparent at a distance of 1 meter is determined by multiplying the sound pressure observed at a remote point where the sound field is spherically divergent by the ratio of the distance of that point, in meters, from the effective acoustic center of the projector, to the reference distance of 1 meter.

Transverse Magnetization. In magnetic recording, magnetization of the recording medium in a direction perpendicular to the line of travel, and parallel to the greatest cross-sectional dimension.

Ultrasonic Coagulation. The bonding of small particles into larger aggregates by the action of ultrasonic waves.

Ultrasonic Cross Grating (Grating). A space grating resulting from the crossing of beams of ultrasonic waves having different directions of propagation. This may be two- or three-dimensional.

Ultrasonic Delay Line (Ultrasonic Storage Cell). A contained medium (usually a liquid, e.g., mercury) in which use is made of the propagation time of sound to obtain a time delay of a signal.

Ultrasonic Detector. A device for the detection and measurement of ultrasonic waves.

Note—Such devices may be mechanical, electrical, thermal, or optical in nature.

Ultrasonic Frequency (Supersonic Frequency[15]). A frequency lying above the audio frequency range. The term is commonly applied to elastic waves propagated in gases, liquids, or solids.

Note—The word "ultrasonic" may be used as a modifier to indicate a device or system intended to operate at ultrasonic frequencies.

Ultrasonic Generator. A device for the production of sound waves of ultrasonic frequency.

Ultrasonic Grating Constant. The distance between diffracting centers of the sound wave which is producing particular light diffraction spectra.

Ultrasonic Light Diffraction. The formation of optical diffraction spectra when a beam of light is passed through a longitudinal wave field. The diffraction results from the periodic variation of the light refraction in the sound field.

Ultrasonic Material Dispersion. The production of suspensions or emulsions of one material in another due to the action of high-intensity ultrasonic waves.

Ultrasonic Space Grating (Grating). A periodic spatial variation of the index of refraction caused by the presence of acoustic waves within the medium.

Ultrasonic Stroboscope. A light interrupter whose action is based on the modulation of a light beam by an ultrasonic field.

Ultrasonics. The general subject of sound in the frequency range above about 15 kilocycles per second.

Underwater Sound Projector. A transducer used to produce sound in water.

Note—Where no confusion will result, the term "underwater sound projector" may be shortened to "projector."

Unidirectional Microphone. A microphone which is responsive predominantly to sound incident from one hemisphere.

Unilateral Area Track. A sound track in which one edge only of the opaque area is modulated in accordance with the recorded signal. There may, however, be a second edge modulated by a noise reduction device.

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[15] Obsolete. *See* **Supersonics.**

Unmodulated Groove (Blank Groove). In mechanical recording, a groove made in the medium with no signal applied to the cutter.

Variable Area Track. A sound track divided laterally into opaque and transparent areas, a sharp line of demarcation between these areas forming an oscillographic trace of the wave shape of the recorded signal.

Variable Density Track. A sound track of constant width and usually, but not necessarily, of uniform light transmission on any instantaneous transverse axis and of which the average light transmission varies along the longitudinal axis in proportion to some characteristic of the applied signal.

Variable-Inductance Pickup. A phonograph pickup which depends for its operation on the variation of its inductance.

Variable Reluctance Microphone (Magnetic Microphone). A microphone which depends for its operation on variations in the reluctance of a magnetic circuit.

Variable-Reluctance Pickup (Magnetic Pickup). A phonograph pickup which depends for its operation on the variation in the reluctance of a magnetic circuit.

Variable-Resistance Pickup. A phonograph pickup which depends for its operation upon the variation of a resistance.

Velocity. Of a point, the time rate of change of a position vector of that point with respect to an inertial frame.

Note—In most cases the approximation is made that axes fixed to the earth constitute an inertial frame.

Velocity Level.[11] In decibels, of a sound, 20 times the logarithm to the base 10 of the ratio of the particle velocity of the sound to the reference particle velocity. The reference particle velocity shall be stated explicitly.

Note—It is to be noted that in many sound fields the particle velocity ratios are not proportional to the square root of corresponding power ratios and hence cannot be expressed in decibels in the strict sense; however, it is common practice to extend the use of the decibel to these cases.

Velocity Microphone. A microphone in which the electric output substantially corresponds to the instantaneous particle velocity in the impressed sound wave.

Note—A velocity microphone is a gradient microphone (*see* **Gradient Microphone**) of order one, and it is inherently bidirectional.

Vertical Recording. A mechanical recording in which the groove modulation is in a direction perpendicular to the surface of the recording medium.

Vibrato. A musical embellishment which depends primarily upon periodic variations of frequency which are often accompanied by variations in amplitude and wave form.

Note—The quantitative description of the vibrato is usually in terms of the corresponding modulation of frequency, amplitude, wave form, or all three.

Vibration Meter (Vibrometer). An apparatus for the measurement of displacement, velocity, or acceleration of a vibrating body.

Volume Indicator. A standardized instrument having specified electrical and dynamic characteristics and read in a prescribed manner, for indicating the volume of a complex electric wave such as that corresponding to speech or music.

Note 1—The reading in vu is equal to the number of decibels above a reference level. The sensitivity is adjusted so that the reference level, or zero vu, is indicated when the instrument is connected across a 600-ohm resistor in which there is dissipated a power of 1 milliwatt at 1,000 cycles per second.

Note 2—Specifications for a volume indicator are given in "American Standard Volume Measurements of Electrical Speech and Program Waves, C16.5-1942."

Volume Velocity. The rate of flow of the medium through a specified area due to a sound wave.

Note—The terms "instantaneous volume velocity," "effective volume velocity," "maximum volume velocity," and "peak volume velocity" have meanings which correspond with those of the related terms used for sound pressure.

Vowel Articulation (Per Cent Vowel Articulation).[6] The per cent articulation obtained when the speech units considered are vowels (usually combined with consonants into meaningless syllables).

Wax. In mechanical recording, wax refers to a blend of waxes with metallic soaps.

See also: **Cake Wax.**

Wax Original (Wax Master).[8] An original recording on a wax surface for the purpose of making a master.

Whole Tone (Whole Step). The interval between two sounds whose basic frequency ratio is approximately equal to the sixth root of two.

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Techniques for Handling Elliptically Polarized Waves with Special Reference to Antennas[*]

V. H. RUMSEY[†], SENIOR MEMBER, IRE, G. A. DESCHAMPS[‡], M. L. KALES[§], AND
AND J. I. BOHNERT[§], MEMBER, IRE

Summary—**Methods are described for representing the elliptical polarization of waves in forms especially convenient for use with elliptically polarized transmitting and receiving antennas. In Part I of this paper V. H. Rumsey shows how an ordinary impedance chart (Carter or Smith) may be used for representation of elliptical polarization. The description of elliptical polarization involves a statement about the relative amplitudes and phases of a pair of vibrating quantities, and this is also what is involved in impedance. Consequently, the whole apparatus of impedance may be neatly adapted for representation of elliptical polarization. In Part II G. A. Deschamps recalls and applies a method of H. Poincaré for representing elliptically polarized light waves. Latitude and longitude on a sphere are used to represent the shape and orientation of the ellipse. A suitable map-projection of the Poincaré sphere then leads to the representation of elliptical polarization on an impedance chart described in Part I. It has already been shown by G. Sinclair that the usual concept of "equivalent length" becomes complex for an elliptically polarized antenna, and in Part II of this paper Deschamps shows how to introduce a real equivalent length for such antennas. In Part III M. L. Kales presents a rather comprehensive theory of elliptical polarization in terms of a three-dimensional vector each of whose components is a phasor. The algebra of such complex vectors facilitates the mathematical handling of elliptical polarization. In Part IV J. I. Bohnert described measuring techniques for elliptically polarized antennas.**

Introduction

H. G. BOOKER[||], SENIOR MEMBER, IRE

ELECTROMAGNETIC waves having elliptical and circular polarization have of course been studied for many years. Not only is there a long history of optical applications of elliptical polarized waves, but down-coming radio waves from the ionosphere are nearly always elliptically polarized and the consequent complications in direction-finding technique are well known. During recent years, however, the deliberate use of circular and elliptically polarized waves for a number of practical purposes has come under serious consideration. The result is that the technique of handling and representing elliptically polarized waves, and more particularly the design and testing of antennas for such waves, has now become a recognizable feature of radio engineering, instead of simply an *ad hoc* problem encountered occasionally by a few specialists.

Elliptically polarized antennas raise a number of problems of representation and measurement that do not arise with simple linearly polarized antennas. For example, in measuring the polar diagram of a linearly polarized antenna we usually measure simply the field strength at a sufficiently large distance as a function of direction: we do not usually bother to make phase measurements. With an elliptically polarized antenna, however, two different field components have to be measured, and it is essential to know the phase difference between them. All of these quantities vary with direction from the antenna, and the question of representing such information on paper comes up for consideration.

Problems involving elliptically polarized antennas have been tackled by Yung-Ching Yeh,[1] by Sinclair,[2] and by others.[3,4] Yeh uses the general theorem of reciprocity to calculate the power received when an elliptically polarized antenna intercepts an elliptically polarized wave of different polarization, in terms of the distant field that would be produced by the antenna when radiating a known power. In Sinclair's paper the concept of equivalent length of an antenna is adapted to antennas radiating and receiving elliptically polarized waves: the equivalent length becomes complex. When appropriate use is made of the complex equivalent length, many of the usual formulas for transmission and reception may be applied to elliptically polarized antennas.

Problems involving elliptically polarized waves and antennas have recently been under study in a half-a-

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[1] Yung-Ching Yeh, "The receiving power of a receiving antenna and the criteria for its design," PROC. I.R.E., vol. 37, pp. 155–158; February, 1948.

[2] G. Sinclair, "The transmission and reception of elliptically polarized waves," PROC. I.R.E., vol. 38, pp. 148–151; February, 1950. Sinclair has replaced the vector $\vec{N}$ in Eq. (2) and (3) of this paper by $\vec{N}_t$, the vector component of $\vec{N}$ transverse to the direction of propagation (see PROC. I.R.E.). He has also pointed out (paper presented at the URSI-IRE Meeting, October, 1949) an alternative formulation: If we let $h' = (\vec{n} \times \vec{h}) Z_0'/Z_a$, where Z_a is the antenna impedance, then the magnetic vector of the transmitted field is

$$\vec{H} = -j \frac{V\vec{h}'}{2Z_0 \lambda r} e^{-jkr}$$

where V is the transmitting voltage. If a plane wave (E_o, H_o) is incident upon the antenna, then the received short circuit current is $I = \vec{H}_o \cdot \vec{h}'$.

[3] W. Sichak and S. Milazzo, "Antennas for circular polarization," PROC. I.R.E., vol. 36, pp. 997–1002; August, 1948.

[4] E. Roubine, "Les Propriétés Directives des Antennas de Reception," *L'Onde Elec.*, pp. 259–266; June, 1950.

dozen or more laboratories, with the result that a number of papers written from rather different points of view have been prepared by various authors. The IRE Professional Group on Antennas and Propagation has therefore attempted to co-ordinate several of these simultaneous and independent approaches to the problems of elliptical polarized antennas, and to present in a single document the points of view of various authors.

The state of elliptical polarization of a plane wave at a point may be described in terms of the amplitudes of vibration of three mutually perpendicular components of the electric (or magnetic) field and their relative phases. In many problems, particularly those connected with antennas, there is no objection to choosing the frame of reference so that the plane of the ellipse coincides with a co-ordinate plane. The state of elliptical polarization can then be measured in terms of the amplitudes of only two perpendicular vector components and their phase difference. If each of these perpendicular vibrations are represented by a complex oscillation function in the usual way, their ratio is a phasor whose modulus is the amplitude ratio of the two vibrations and whose argument is their phase difference. Such a phasor is frequently a convenient way of describing a state of elliptical polarization, and is the most common method that has been used in the past. The phasor may be represented in a complex plane in the usual way, so that the various points in the plane correspond to the various elliptical polarizations that are possible. This technique is explored by V. H. Rumsey in Part I of this paper. He makes the highly important observation that the handling of these polarization ratios is practically identical with the handling of impedances. This may easily be seen if one thinks of field impedance rather than circuit impedance. Field impedance involves the ratio of a component of electric field to another component of magnetic field. But polarization ratio involves the ratio of a component of electric field to another component of electric field. Both therefore involve the ratio of two different components of the electromagnetic field. The upshot is that practically the entire apparatus of impedance may be taken over for discussion of elliptical polarization, including the Carter and Smith impedance charts. It is this approach to problems involving elliptical polarization that V. H. Rumsey presents in Part I, and engineers who are familiar with impedance charts should find this section particularly interesting.

It happens that Rumsey's method of adapting impedance charts for representation of elliptical polarization is closely bound up with a method introduced long ago by H. Poincaré for picturing elliptical polarization in optics. Poincaré uses a special sphere on which to exhibit elliptical polarization. Latitude and longitude on the sphere are used to represent two angles that describe the shape and orientation of the ellipse. One of these angles is twice the orientation angle of the major axis relative to the co-ordinate system; the other is twice the angle whose tangent is the axis ratio of the ellipse. Poincaré's method of representing elliptical polarization on a sphere is exploited by G. A. Deschamps in Part II of this paper. It is, of course, possible to use any standard map projection to convert the Poincaré spherical representation into a plane diagram. Two such projections are described by Deschamps, one of which is simply an impedance diagram as adapted by Rumsey in Part I.

The most comprehensive theory of elliptical polarization so far available is presented by M. L. Kales in Part III of this paper. The three mutually perpendicular vibrations that in general describe the state of elliptical polarization of a wave at a point may be represented by three complex numbers by introducing the usual complex oscillation functions. These three complex numbers form the three components of a vector in the usual three-dimensional sense. Each component of this vector is, however, a vector in the usual complex number sense. Elliptical polarization in general involves therefore a three-dimensional vector each of whose components is a phasor. The algebra for handling such complex vectors is developed in Part III and applied to various problems in connection with elliptically polarized antennas. J. I. Bohnert further describes in Part IV the techniques that have been developed at the Naval Research Laboratory for making measurements on elliptically polarized antennas.

Terminology and Notation

It is perhaps desirable to mention at the outset several quantities that will appear in the various parts of this paper. The ratio of the principal axes of an ellipse will be referred to as the *axial ratio* and will be denoted by r. Axial ratio may be less or greater than unity according to convenience. If the axial ratio is taken to be less than unity, then the angle $\alpha = \tan^{-1} r$ will be called the *ellipticity-angle*. It determines the shape of the ellipse. 2α is the angle between the diagonals of a rectangle which encloses the ellipse and has its sides parallel to the principal axes. β will be an angle which defines the orientation of the ellipse. It is the angle between the major axis and a specified initial line. The angles α and β together specify the shape and orientation of the ellipse.

It will often be desirable to think of an elliptically polarized vector as having two orthogonal vector components which vibrate with different amplitudes and in different phases. If these two vector components are represented by complex oscillation functions in the usual way, their ratio will be called the *polarization-ratio* and denoted by P. P is a complex number whose modulus is the amplitude ratio of the perpendicular linear vibrations and whose argument is their phase difference. In Part I Rumsey will find it convenient to work in terms of jP rather than P.

The *equivalent length* of an antenna is the length of a vector whose scalar product with the electric vector of an incident plane wave gives the open-circuit voltage at the terminals of the antenna when used for reception.

Part I—Transmission Between Elliptically Polarized Antennas*

V. H. RUMSEY†, SENIOR MEMBER, IRE

MANY PROBLEMS involving the transmission of electromagnetic waves can be solved very elegantly by making use of the impedance concept which reduces the field problem to a transmission line problem. The analysis of impedance transformation occurring in transmission line theory can again be simplified by working in terms of reflection coefficient. The impedance concept is successful in such applications largely because the tangential components of the electric and magnetic fields are continuous at a surface separating two different media. For the same reason, we may expect the polarization ratio P, defined as the ratio of two orthogonal tangential components of electric field, to be equally valuable in the analysis of polarization. If we think of P as analogous to impedance, then we find that the analogue of reflection coefficient is the ratio of the right-handed and left-handed circularly polarized components which are equivalent to the linearly polarized components used to define P. This is demonstrated in the following section.

REPRESENTATION OF POLARIZATION[5]

The wave functions $e^{\pm j(\omega t - \beta z)}$ may be interpreted as two circularly polarized waves of opposite sense propagated along the z axis. In this representation the real part represents the x component and the imaginary part the y component of the field vector. The connection between the circularly polarized and linearly polarized representations is readily established. An arbitrary plane wave may be described in terms of x and y components, say,

$$E_x = a \cos(\omega t + \phi_1) \quad E_y = b \cos(\omega t + \phi_2), \tag{1}$$

or in terms of left and right circular components, L and R,

$$E_L = \alpha e^{-j(\omega t + \theta_1)} \qquad E_R = \beta e^{j(\omega t + \theta_2)}, \tag{2}$$

the connection between the representations being defined by

$$E_L + E_R = E_x + jE_y. \tag{3}$$

Equating coefficients of $e^{\pm j\omega t}$ gives

$$2R = x + jy \tag{4}$$

$$2L = x - jy, \tag{5}$$

where

$$x = ae^{j\phi_1} \qquad y = be^{j\phi_2} \tag{6}$$

$$L = \alpha e^{j\theta_1} \qquad R = \beta e^{j\theta_2}. \tag{7}$$

Let

$$p = \frac{jy}{x} = jP \qquad q = \frac{L}{R}. \tag{8}$$

Then

$$q = \frac{1-p}{1+p} \qquad p = \frac{1-q}{1+q}. \tag{9}$$

The transformation from p to q is thus identical to the transformation from current reflection coefficient to normalized impedance. Note that p is j times the polarization ratio P. In view of the symmetry of the transformation we can think of p, and vice versa q, as reflection coefficient or impedance. The choice is determined by the physical situation. The simplest type of impedance transformation is that due to a uniform section of transmission line, which causes a phase change at constant amplitude of reflection coefficient. The simplest type of polarization transformation is that due to rotation of the antenna producing the elliptically polarized wave which causes a phase change at constant amplitude of q. In order to make the best use of existing techniques, it therefore seems better to consider q as the analogue of current reflection coefficient. If the polarization is specified in terms of p, the complex ratio

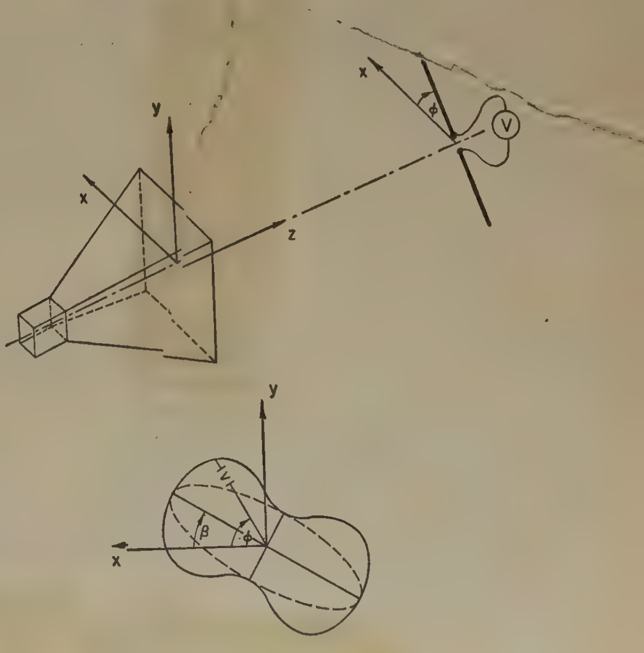

Fig. 1—Polarization measurement.

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The work described in this paper was carried out, in part, under a contract between the Wright-Patterson Air Force Base of the Air Materiel Command and the Ohio State University Research Foundation.

† Ohio State University, Columbus, Ohio.

[5] The material in this section was presented in different form at the joint URSI-IRE Meeting by V. H. Rumsey and T. E. Tice; October, 1949.

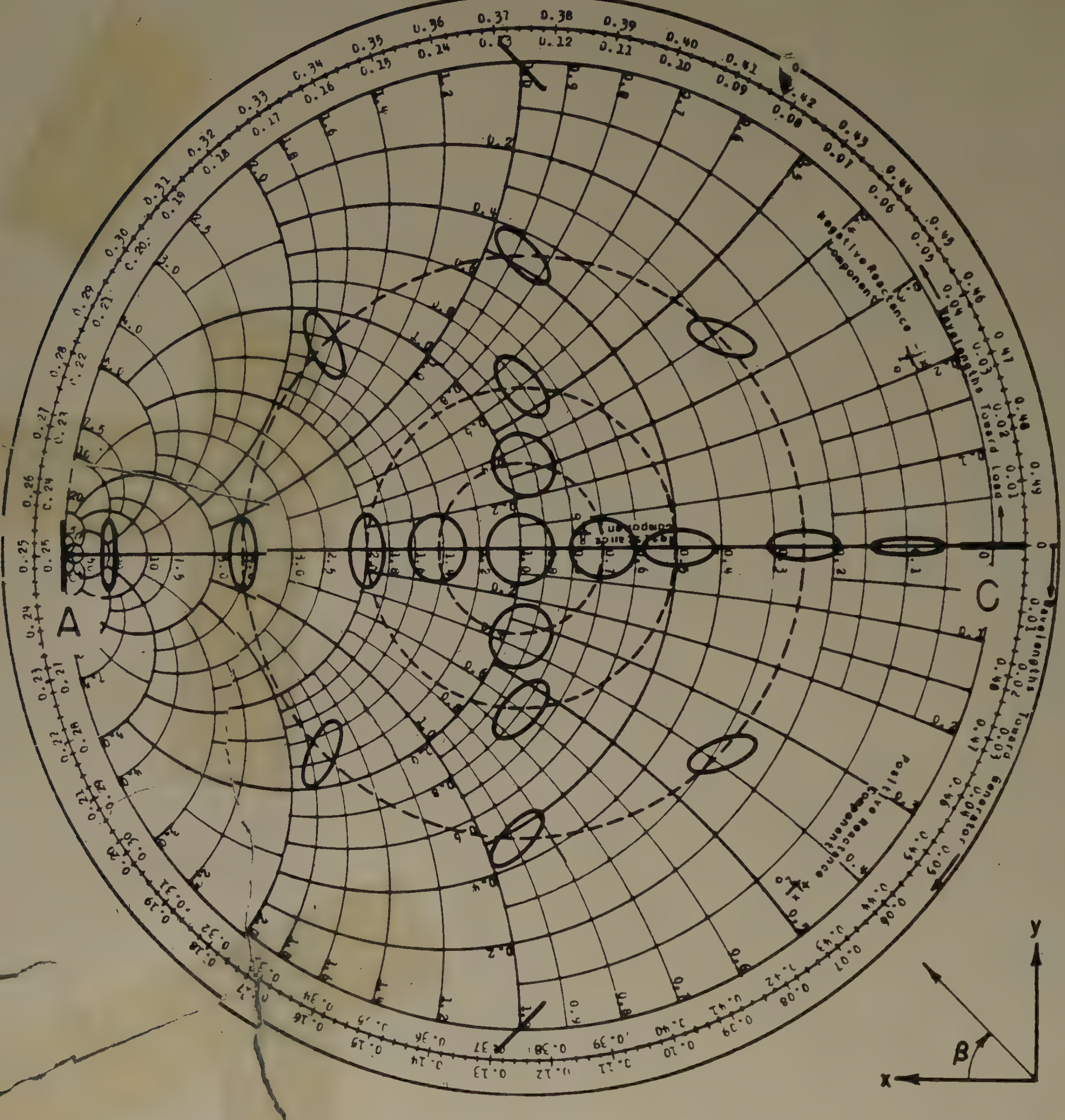
A
C
y
x
β
Negative Reactance Component
Positive Reactance Component
Wavelengths Toward Load
Wavelengths Toward Generator
q Plane Representation

Fig. 2—q-plane representation.

of the two orthogonal linear components, then q, the complex ratio of the two equivalent circularly polarized components, is equal to the reflection coefficient obtained by plotting p as an impedance on the Smith chart. The analogy is illustrated by Figs. 1 to 4. Fig. 1 shows how the polarization is specified. The co-ordinate axes are fixed to the antenna which transmits the elliptically polarized wave along the positive z axis. The polarization ellipse is determined from measurement of the variation of voltage V induced in a linear receiving antenna as a function of orientation ϕ in the plane normal to the z axis. Thus $V \sim Le^{i\phi} + Re^{-i\phi}$. The sense of rotation of right or left circular polarization is implied by (2): the field vector rotates about the positive z axis in a right-handed sense for right circular polarization in accord with the IRE definition. Fig. 2 shows how the orientation and shape of the polarization ellipse are represented using the Smith Chart as the q plane. Fig. 3 illustrates the representation using the Carter diagram as the p plane. Fig. 4 illustrates the analogy between the phasors associated with impedance and polarization. Given the point P in the q plane, then all

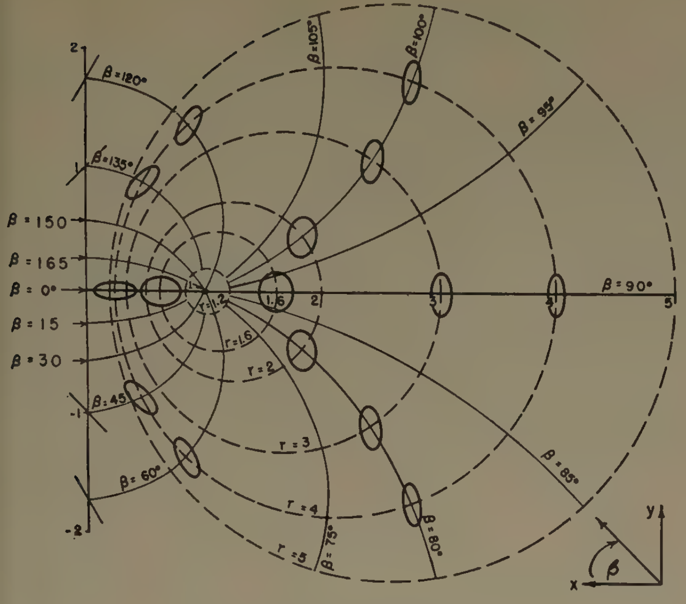

Fig. 3—p-plane representation.

four of the component phasors are represented relative to each other in magnitude and phase as shown in Fig. 4.

Some obvious consequences of this exact analogy follow. For points on the p plane:

1. Points in the right half-plane represent right-handed polarization and points in the left half-plane represent left-handed polarization.
2. Points on the vertical axis represent linear polarization at various angles.
3. Circular polarization is represented by the points (1, 0) and (−1, 0).
4. Constant axial-ratio contours are identical to the circles of constant standing-wave ratio (SWR) on the Carter impedance chart. The axial ratio is equal to the SWR obtained by treating p as an impedance.

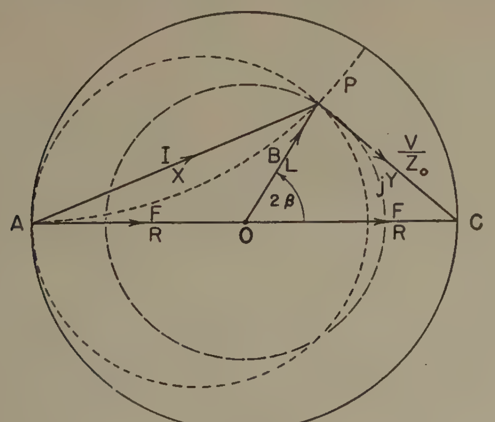

Fig. 4—Impedance: F=forward current wave
B=backward current wave
I=resultant current
V=resultant voltage.
Polarization: R=right circular wave
L=left circular wave
X= horizontal linear wave
Y=vertical linear wave.

For points on the q plane:

1. We have right-handed polarization for all points inside the unit circle, and left-handed polarization for all points outside.
2. The origin represents right-circular polarization, and the point at infinity represents left-circular polarization.
3. Constant axial-ratio contours are identical to the circles of constant SWR on a Smith chart. The axial ratio is equal to the SWR obtained by treating q as a reflection coefficient.
4. A point on the unit circle represents linear polarization at an angle equal to one-half the polar angle.
5. The angle β between the x axis and the major axis of the polarization ellipse is related to the polar angle θ on the q plane by the simple relation $2\beta=\theta$.
6. The locus of the points representing polarizations for which $|x/y|$ is constant is the set of circles passing through the points $q=\pm 1$ (the short and open-circuit points); the orthogonal set of circles is obtained if the phase of x/y is constant.

Although the polarization is specified uniquely by p or q, as it stands the representation requires the entire complex plane; whereas conventional impedance charts require only the interior of the unit circle in the reflection coefficient plane. Obviously all polarizations can be represented by points inside the unit circle by interchanging left-handed and right-handed senses whenever a point falls outside. Thus representation on the conventional impedance charts requires two kinds of points, one kind representing polarization according to the definition of p or q (8), the other representing exactly the same polarization, except that right and left senses are interchanged. Such a representation would also be required in transmission line theory in order to specify the "impedance" of a power generator as well as the more conventional power absorber.

THE ANALOGY BETWEEN POLARIZATION AND IMPEDANCE MEASUREMENT

Another valuable consequence of the analogy between polarization and impedance is the possibility of taking over many of the techniques of impedance measurement and applying them directly to the measurement of polarization. To do this, we note the analogies represented by Table I.

TABLE I

Impedance	Polarization
Matched load	Circularly polarized wave
Short circuit	Linearly polarized wave
Directional coupler	Circularly polarized receiving antenna
Voltage (or current) probe	Linearly polarized receiving antenna
Distance along transmission line	Orientation angle of antenna

The analogy between components given in Table I may be used to deduce techniques of polarization measurement from well-known techniques of impedance measurement. A few representative examples are given in Table II.

TABLE II

Impedance	Polarization
Slotted line	Rotating linear antenna
3 or more fixed probes[6]	3 or more linearly polarized antennas at fixed orientations
2 opposite directional couplers	2 opposite circularly polarized antennas

It is interesting to note that the first two methods involve amplitude measurements only, and do not determine the polarization uniquely because there is an ambiguity in the sense of rotation. In principle, there is the same ambiguity associated with the determination of impedance but this is usually not of practical importance because the ambiguity is between a power absorber and a power generator. The third method involves a phase measurement as well as amplitude measurements, and gives a unique result.

TRANSMISSION BETWEEN ELLIPTICALLY POLARIZED ANTENNAS

The performance of an elliptically polarized antenna, when it is used as a component in transmission over a radiation path, may be specified completely by three parameters denoted by z, G, and p. The complex number z represents the input impedance and needs no further explanation. The parameter G is a real number, equal to the ratio of the power radiated in a given direction to the average power radiated in all directions, and represents the power gain of the antenna. The complex number p (or the alternative q) is a function of direction and is obtained by measuring the polarization of the waves transmitted by the antenna in that direction. It is the effect of polarization on transmission between antennas with which we are concerned in this section.

The analysis of transmission between elliptically polarized antennas largely depends on careful specification of the co-ordinate system. Let the z axes of the transmitter and receiver point toward each other along the path of propagation. For the sake of simplicity, we can choose the other co-ordinate axes so that the x axes of the two antennas are parallel, pointing in the same direction, and therefore the y axes are parallel, pointing in opposite directions. The voltage V induced in one antenna due to transmission from the other can now be represented as

$$V = T(L_A'L_B + R_A'R_B), \tag{10}$$

where T is a transmission coefficient depending on the range and antenna apertures.[7] The parameters L_A' and R_A' are determined by measuring the polarization of the wave transmitted by antenna A along its z axis, and are defined with reference to the above co-ordinate system by means of (2) and (7). The parameters L_B and R_B are similarly defined for antenna B by measuring the polarization of the wave it transmits along its z axis. This formulation has the advantage that it is not necessary to specify which antenna is transmitting.

The formula for V when the antennas are at an arbitrary orientation is readily established. Let antenna A be given a right-handed rotation through an angle γ about its z axis, the x and y axes rotating with the antenna. The values of L_A' and R_A' in (10) are referred to the original set of axes. Thus

$$L_A' = L_Ae^{-i\gamma} \qquad R_A' = R_Ae^{i\gamma},$$

where L_A and R_A are measured with respect to the new position. Omitting the constant factor T:

$$V = L_AL_Be^{-i\gamma} + R_AR_Be^{i\gamma}, \tag{11}$$

or

$$V = R_AR_Be^{i\gamma}(1 + q_Aq_Be^{-2i\gamma}). \tag{12}$$

As one antenna is rotated relative to the other, the variation of received voltage depends on γ only, all other quantities in (11) and (12) remaining fixed, because L_A, L_B, R_A, and R_B are measured with respect to axes fixed to the antennas.

Equation (12) shows that the variation of V with relative orientation γ has the same functional form as the variation of voltage picked up by a linear antenna in the field of an elliptically polarized antenna whose q equals the product q_Aq_B.

The result may be stated as follows:

Theorem 1. The voltage received by an elliptically polarized antenna due to an incident elliptically polarized wave varies as the antenna is rotated about the direction of propagation in the same way as the voltage picked up by a linearly polarized antenna receiving an elliptically polarized wave.

Theorem 2. The orientation and axial ratio of the *effective* ellipse obtained by rotating an elliptically polarized receiving antenna A, relative to an elliptically polarized transmitting antenna B, are represented by an effective q given by $q = q_Aq_B$.

Theorem 2 has some useful applications in the design of calibrated phase shifters. A standard phase shifter may be constructed by connecting the input to some generator of a circularly polarized field, and the output to a linearly polarized detector of variable orientation. Then the phase shift between input and output varies as the orientation of the linear detector. In practice it is difficult to obtain good accuracy, owing to the difficulty of producing a field which is exactly circular. Theorem 2 suggests how this might be greatly improved; for example, suppose that a practical arrangement gives an elliptically polarized field with an axial ratio of 1.1 instead of a perfectly circular field. With a linearly polarized detector the effective q of the system has magnitude 0.05, resulting in a voltage variation of 10 per cent and a phase error of about 3° from the ideal. With an elliptically polarized detector having the same axial ratio as the generator the effective q has magnitude $(0.05)^2$, resulting in a voltage variation of 0.5 per cent and a phase error of about 0.15°. Thus, for the same practical limitations, the accuracy of such phase shifters can be greatly improved by making the q's of both the generator and detector as small as possible.

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[6] Combined Research Group Report CRG 96, "Methods of Impedance Measurement at UHF," V. H. Rumsey, issued from Naval Research Laboratory, October, 1945.

[7] Compare G. Sinclair, "The transmission and reception of elliptically polarized waves," Proc. I.R.E., vol. 38, p. 148; February, 1950, where a corresponding formula for linear component representation is given. The circular component representation is preferred here, because it is best suited for treating rotation of the antenna, and because the instantaneous power in a circularly polarized wave is independent of time.

A further advantage in making the q's the same is the improvement in power transfer (see Theorem 4 below).

Theorem 3. There is no transfer of power between antennas A and B when $q_A q_B = -1$ the q's being measured with reference to x or y axes pointing in the same direction. This is the condition for cross-polarized antennas.

In terms of the p representation the condition implies $p_A p_B = -1$.

When p and q are plotted as impedance and reflection coefficient, A and B are cross-polarized when A corresponds to the admittance of B with right and left senses interchanged. Thus, cross-polarized antennas have opposite senses with the same polarization ellipses oriented at right angles.

Theorem 3a. The effective axial ratio of two cross-polarized antennas is zero. The polarization measurement of one by means of the other cannot be distinguished from the measurement of one linear antenna by means of another linear antenna.

Optimum Power Transfer

Our problem is to determine the polarization of A which generates maximum voltage in B for a fixed power in the wave transmitted by A. It is readily shown that the power in the transmitted wave is proportional to

$$L_A L_A^* + R_A R_A^* = P_A, \tag{13}$$

where the star denotes the complex conjugate. The receiving antenna B is fixed, and the polarization of A is adjusted, keeping P_A constant until the maximum voltage is generated in B. This suggests that we normalize $|V|^2$ [see (11)] with respect to P_A as follows:

$$VV^* \sim \frac{(L_A L_B + R_A R_B)}{L_A L_A^* + R_A R_A^*} (L_A^* L_B^* + R_A^* R_B^*).$$

(A and B are measured with respect to the same x axis.) However, the relation so obtained applies specifically to the case where A transmits and does not take account of the other possibility. A symmetrical formula applicable whichever antenna transmits is:

$$VV^* = \frac{L_A L_B + R_A R_B}{L_A L_A^* + R_A R_A^*} \cdot \frac{L_A^* L_B^* + R_A^* R_B^*}{L_B L_B^* + R_B R_B^*}, \tag{14}$$

where the extra term in the denominator obviously makes no difference in the particular case where A transmits.

If the vector A has components L_A and R_A, etc., (14) may be expressed more concisely in the scalar product notation:

$$|V| = \frac{|A \cdot B|}{|A||B|}. \tag{14a}$$

In terms of the p's and q's defined by (8), (14) becomes:

$$\begin{aligned} VV^* &= \frac{1 + q_A q_B}{1 + q_B q_B^*} \cdot \frac{1 + q_A^* q_B^*}{1 + q_A q_A^*} \\ &= \frac{1 + p_A p_B}{1 + p_A p_A^*} \cdot \frac{1 + p_A^* p_B^*}{1 + p_B p_B^*}. \end{aligned} \tag{15}$$

Examination of (15) shows that V is a maximum when

$$q_A = q_B^* \qquad p_A = p_B^*. \tag{16}$$

Theorem 4. The maximum transfer of power between antennas A and B occurs when their polarization parameters p and q are conjugate complex numbers, the polarization being measured with respect to the same x axis.

We see that the magnitude of V in (15) is unity when $q_A = q_B^*$ or $p_A = p_B^*$. Thus V in (15) is the voltage induced in A due to an incident wave from B, relative to the maximum voltage that could be induced in A by adjusting the polarization of B keeping the power in the incident wave constant

Theorem 4a. The effective q of two *matched* antennas is the square of the magnitude of q for one antenna.

The result of Theorem 4 is analogous to the condition for optimum power transfer between a generator and load. It suggests that we might apply the matching concept to elliptically polarized antennas, two such antennas being *matched* when they satisfy the conditions of Theorem 4.

The problem of transmission from one point to another illustrates the need for unification of impedance and polarization concepts. In order to obtain optimum transmission, the transmitting antenna is matched to the generator, the receiving antenna is matched to the transmitting antenna and the receiving load is matched to the receiving antenna. The first and third problems are impedance matching problems. The second is polarization matching problem. When the polarization is specified by the parameter p and the impedance by the parameter z_r the condition for an impedance or polarization match is that the parameter of the sending end should be the complex conjugate of the parameter at the receiving end.

It is instructive to examine the implications of Theorem 4, because at first sight it might suggest an unsuspected difference between the design of transmitting and receiving antennas. First, consider a given transmitting antenna whose major axis of polarization is parallel to the x axis. Then both p and q are real. Theorem 4 states that the matched receiving antenna is identical in polarization to the transmitter, the receiver being oriented so that its x axis coincides with that of the transmitter (but the y axes are opposed). The apparent difference between transmitter and receiver occurs when the transmitter has a polarization ellipse inclined to its x axis at some angle. Then Theorem 4 says that the receiver should have the same polarization ellipse but inclined at the supplementary angle. However, when the two antennas are set up for transmission from one to the other with x axes pointing in the same direction, the two polarization ellipses have the same orientation in space, but supplementary orientations with respect to axes fixed to the antennas.

Although Theorem 4 may appear obvious, it is not trivial. For instance, if we have two identical elliptically polarized rectangular horns, then optimum transmission from one to the other is not obtained when they are set up in identical orientations, unless the major axis of the polarization ellipse happens to be parallel to one pair of sides of the rectangular aperture.[8]

VOLTAGE INDUCED IN ELLIPTICALLY POLARIZED ANTENNAS DUE TO REFLECTORS

The effect of an infinite plane reflector is readily treated. We choose a z axis normal to the reflector. The effect of the reflector may be represented by the image of the antenna, which differs from its object only in reversal of the z axis; that is, the image of the axes on the antenna is left-handed. Thus the image is identical to the antenna, except that the sense of all rotations is reversed. If subscript O refers to the object and subscript I to the image, then,

$$q_I q_O = 1 \qquad p_I + p_O = 0$$
$$L_O = R_I \qquad L_I = R_O.$$

Substitution in (12) gives $V = 2R_O L_O$.

While we have considered a plane reflector for the sake of simplicity, it is clear that the same result is obtained for reflection from any body which has the same reflection coefficient for all polarizations.

Theorem 5. The voltage developed in an antenna due to reflection from a target which reflects all polarizations equally varies as the product of the left- and right-handed circularly polarized components transmitted by the antenna.

A double reflection from two plane reflectors at right angles has some interesting features. With a double nonpolarized reflector, e.g., a double reflection in the corner of an infinite rectangular wedge, there occurs a double reversal of sense of rotation, so that the image and object are identical with z axes pointing in opposite directions. Thus the image and object are *matched* at some orientation of the double reflector with respect to the antenna.

Theorem 6. The variation of voltage induced in an antenna as it is rotated about the direction of propagation, due to a double reflection from a nonpolarized reflector, corresponds to an effective q equal to the square of the antenna q.

In the general case there is an arbitrary transformation of polarization on reflection. If subscripts i and r refer to the incident and reflected waves,

$$q_r = \frac{Eq_i + F}{Gq_i + H}$$

where E, F, G, and H are constants depending on the reflecting body.

[8] Compare Yung-Ching Yeh, "The receiving power of a receiving antenna and the criteria for its design," Proc. I.R.E., vol. 37, pp. 155–158; February, 1949.

Part II—Geometrical Representation of the Polarization of a Plane Electromagnetic Wave*

G. A. DESCHAMPS†

WE SHALL consider only plane electromagnetic waves of frequency $2\pi\omega$ and of a given direction of propagation Oz. Completing the system of co-ordinates with Ox, Oy, we assume that Oy is vertical for the sake of definiteness. The extremity of the electric vector in such a wave, at the reference point O, will describe, in the plane xOy an ellipse ϵ (which may sometimes reduce to a straight line or a circle). Two waves are said to be in the same *state of polarization* if the two corresponding ellipses are similar, similarly oriented, and described in the same sense.

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The horizontal and vertical components of the electric vector can be represented, at time t, a the real parts of

$$Xe^{j\omega t} \quad \text{and} \quad Ye^{j\omega t}$$

where X and Y are complex numbers. The complex number $P=Y/X$, *polarization ratio*, specifies in a simple way the polarization, as defined above. However, it was shown by Poincaré[9] that there is advantage, for certain problems in optics to make use of a geometrical picture in which each state is represented by a point on a sphere. The purpose of this paper is to adapt this point of view to radio waves and antennas and to indicate its usefulness in the solution of various problems.

Description of Poincaré Spherical Representation

The shape of the ellipse ϵ, locus of the extremity of the electric vector, can be specified by the *axial ratio*

$$r = \frac{\text{minor axis}}{\text{major axis}} \cdot$$

To indicate at the same time the direction in which ϵ is described, we shall give to this ratio the sign + or −, according to the sense of rotation. We can then introduce the *ellipticity angle*

$$\alpha = \arctan r$$

always taken between −45°+45°. The orientation of the ellipse will be defined by the *orientation angle* β, angle between Ox and the major axis. We can choose β positive and less than 180°.

The two angles α and β completely specify the state of polarization. Poincaré's representation consists in taking 2β and 2α as longitude and latitude of a point on a sphere. This gives a one-to-one correspondence; each point of the sphere represents a state and different points represent different states. Fig. 5 shows a few examples.

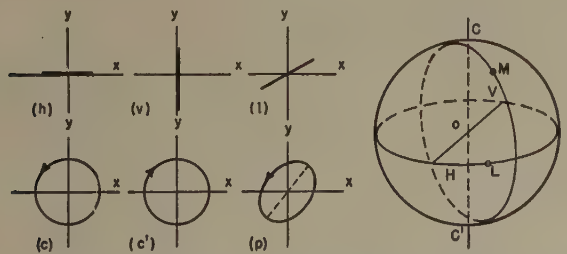


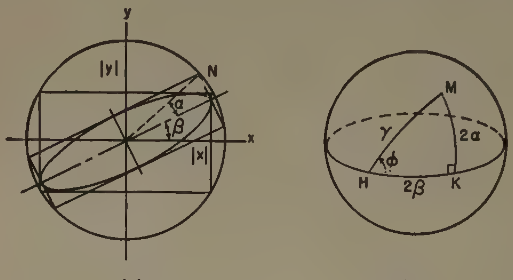
Fig. 5—Representation of various polarizations on Poincaré's sphere. h, v, l, linear polarizations give points H, V, L on the equator; c and c' give the two poles C, C'; an arbitrary point M corresponds to some elliptical polarization p.

Relations Between Various Parameters of the Ellipse

The polarization ratio P can be deduced from the parameters β, α (orientation and ellipticity angles). If P is written in the form $\tan\gamma e^{j\phi}$, the equations are

$$\begin{cases} \cos 2\gamma = \cos 2\alpha \cos 2\beta \\ \tan\phi = \tan 2\alpha \csc 2\beta. \end{cases} \tag{17}$$

These well-known formulas of spherical trigonometry show that the *difference of phase* ϕ between the vertical and the horizontal components of the field is the angle H on the sphere (Fig. 6), while the *amplitude ratio* $\tan\gamma$ is determined by the distance $HM=2\gamma$.



(a) (b)

Fig. 6—Representation of the parameters α, β, γ, ϕ as elements of a spherical triangle.

By solving (17) for α and β we deduce

$$\begin{aligned} \tan 2\beta &= \tan 2\gamma \cos\phi \\ \sin 2\alpha &= \sin 2\gamma \sin\phi, \end{aligned} \tag{18}$$

giving orientation and ellipticity as functions of P. It is then easily seen that the correspondence between P and the point M on Poincaré's sphere can be obtained by a stereographic projection of the complex plane of P onto a sphere.

It is to be noted that the simple form of (17) and (18) make them immediately adaptable to slide-rule computation.

Amplitude of an Elliptically Polarized Wave

We have so far described the shape and orientation of the ellipse ϵ but not its size. The natural parameter for this purpose is the amplitude E defined by

$$E^2 = |X|^2 + |Y|^2, \tag{19}$$

since this represents, when multiplied by the intrinsic admittance of space, the power density (watts/m^2) in the wave. With this parameter the two components of the polarized wave can be written

$$\begin{aligned} X &= E\cos\gamma \\ Y &= E\sin\gamma e^{j\phi}, \end{aligned} \tag{20}$$

neglecting a constant phase factor.

In Fig. 6(a) $E=ON$ and it reduced to the amplitude in the ordinary sense for linear polarization.

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[9] H. Poincaré, "Théorie Mathématique de la Lumière," pp. 282–285; 1889.

POLARIZATION AND EFFECTIVE HEIGHT OF AN ANTENNA IN A GIVEN DIRECTION

The receiving properties of an antenna for a given direction are described by the voltages which are induced in it by waves of unit amplitudes and of polarizations respectively horizontal and vertical. If X' and Y' are these voltages (complex numbers) we can, neglecting a constant phase factor, write them as:

$$\begin{aligned} X' &= h \cos \gamma' \\ Y' &= h \sin \gamma' e^{-j\phi'}. \end{aligned} \tag{21}$$

The voltage induced in the antenna by some plane wave of arbitrary polarization (20) will be:

$$V = \left| XX' + YY' \right| = Eh \left| \cos \gamma \cos \gamma' + \sin \gamma \sin \gamma' e^{j(\phi - \phi')} \right|.$$

If we let the factor of Eh be $\cos \delta$ [with $0 \leqq \delta \leqq \pi/2$], we find

$$\cos 2\delta = \cos 2\gamma \cos 2\gamma' + \sin 2\gamma \sin 2\gamma' \cos (\phi - \phi'),$$

which is a classical formula of spherical trigonometry. It shows that if we represent on Poincaré's sphere the points M and M' corresponding to the polarization ratios $\tan \gamma e^{j\phi}$ and $\tan \gamma' e^{j\phi'}$, 2δ is the angular distance (MM') between the points M and M' and therefore:

$$V = Eh \cos \frac{(MM')}{2} \cdot \tag{22}$$

This important result[10] is a generalization of the formula $Eh \cos(\beta - \beta')$ for a dipole of orientation β' and a linearly polarized wave of orientation β. In this special case, as in general, the coefficient h has the dimension of a length and can be called the *effective height* of the antenna while the components (21) are the co-ordinates of the vectorial effective height considered by G. Sinclair.[10]

The use of a minus sign in (21) and the representation of the polarization of the antenna by a ratio which is the complex conjugate of Y'/X' should be noted. It is related to the reversal of time which transforms the transmitting antenna into a receiving antenna (compare to Sinclair, p. 50). If incident waves are referred to a left-handed or direct system $Oxyz$ where Oz is the direction of propagation; in order to compare ratios, we have to use a right-handed system $Oxyz'$ for the wave radiated by the antenna in the direction Oz' opposite to Oz. Any choice of a direct system ($Oxy'z'$, for instance) for the radiated wave would be arbitrary. The polarization ratio for the radiated wave is indeed Y'/X' (measured in the $Oxyz'$ system) but we adopt the convention that a ratio measured in a right-handed system is represented on the sphere by its complex conjugate. This has the following advantages: (1) It relates the handedness of polarization with regions of the sphere in a manner independent of the orientation of the reference system (provided its Oz axis indicates the sense of propagation). (2) It leads to the simple formula (22).

The condition for maximum transfer between two antennas A and B is that the polarization ratio of A in a left-handed system be the complex conjugate of the polarization ratio of B in the corresponding right-handed system ($OxOy$ axis coincide). This is Rumsey's Theorem 4, page 539. By changing the ratio for B to its conjugate the condition becomes the coincidence of the representative points on the sphere.

As an illustration, the transfer between two circularly polarized antennas is maximum when they are both right-handed or both left-handed, and are therefore represented by the same pole of the sphere with the convention made above. By normal reflection, the handedness of a wave is inversed, and therefore a circularly polarized antenna does not "see" its image in a mirror.

One consequence of (22) is that the metric on the Poincaré sphere is the most natural to evaluate the nearness of polarization states. If one wants, for instance, to construct an antenna having a certain polarization, circular or other, and if the realization is not perfect, the best criterion to apply is to ask how far away, on a Poincaré's sphere, is the result from the desired polarization. A look at the picture on the sphere can also tell us, in the case of synthesis by means of two dipoles, for instance, if it is better to modify their relative phasing or their relative amplitude to approach a certain goal. Comparing polarization ratios would often give a wrong impression, since they can be widely different for antennas almost identical as far as their receiving properties are concerned.

For any antenna there is a polarization which is not received, namely, that which is represented by the opposite point on the sphere. In fact, we than have $(MM')/2 = 90°$ and therefore $V = 0$. M and M' are said to represent crossed polarizations.

DETERMINATION OF THE POLARIZATION STATE OF A WAVE

A number of problems can be solved by using the spherical representation. We shall take the following as an illustration.

One method to find the polarization of a wave would be to receive it on two antennas of known polarizations

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[10] Equation (22) is equivalent to, but simpler, than others given, for instance, by W. Sichak and S. Millazo "Antennas for circular polarization," PROC. I.R.E., vol. 36 pp. 997–1001, August, 1948; by G. Sinclair "The transmission and reception of elliptically polarized waves," PROC. I.R.E., vol. 38, p. 151, February, 1950; and by M. L. Kales in Part III of this paper, pp. 547–549. It can also be related to a similar formula using Stokes parameters. For purely polarized waves I, M, C, S have values: I, $I \cos 2\beta \cos 2\alpha$, $I \cos 2\beta \sin 2\alpha$ $I \sin 2\beta$ (See, for instance, F. Perrin, "Polarization of light scattered by isotropic opalescent media," *Jour. Chem. Phys.*, vol. 10, pp. 415–427, July, 1942; where I can be the power density in the wave and $I^2 = M^2 + C^2 + S^2$. Similarly a purely polarized receiving antenna can be described by I', M', C', S' such that $I'^2 = M'^2 + C'^2 + S'^2$ and I' is the effective cross section A of the antenna. The power received is $(\frac{1}{2})(II' + MM' + CC' + SS') = (\frac{1}{2}) IA (1 + \cos 2\delta) = IA \cos^2 \delta$ which agrees with equation (22).

M_1 and M_2 and of effective heights h_1 and h_2 compare the amplitudes received. The result

$$\frac{h_1 \cos \dfrac{(M_1M)}{2}}{h_2 \cos \dfrac{(M_2M)}{2}}.$$

The locus of the unknown polarization M, whe ratio is constant, is a circle.

We, therefore, need a third antenna P_3 which by same method gives another circle. There is stil ambiguity since the circles intersect in two points. (I the antennas are linearly polarized, this ambiguit only one of sense of rotation.) A fourth antenna sol the problem completely, provided its polarization is n in the plane $P_1P_2P_2$.

TRANSFORMATION OF POLARIZATION

When a plane wave is scattered into another pla wave or goes through a nonisotropic medium, its polarization state changes and this can be expressed by a linear transformation such as:

$$\begin{pmatrix} X' \\ Y' \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix}.$$

The polarization ratio P is, therefore, transformed according to a bilinear transformation as indicated in Part I, page 535.

There is a special case where this transformation is simply pictured on Poincaré's sphere.[11] If the power $|X'|^2+|Y'|^2$ is equal to $|X|^2+|Y|^2$ (lossless transformation) the matrix is unitary and it is known[12] that it can be represented by the rotation of a sphere precisely by using the stereographic projection which leads to Poincaré's sphere.

To illustrate this, let us consider wave propagation in a circular waveguide. The state of polarization is the ratio of wave amplitudes in two orthogonal modes X and Y. If a longitudinal ridge placed in the guide slows the X mode with respect to the Y mode, the effect of a certain length of guide is to increase the phase difference between X and Y by a fixed amount ϕ. On the sphere this is simply expressed by a rotation of angle ϕ about HV. If the ridge is placed in the orientation β with respect to Ox, the effect would be a rotation of the sphere about the axis of longitude 2β.

It is known from geometry that any rotation can be produced by the product of two rotations of this latter type, therefore a transducer which produces *any* lossless transformation of polarization can be obtained by placing in series two pieces of circular ridged wave-

then to

guide of proper lengths. By the same method a phase changer described by Fox[13] can be analyzed and others having various broad-band properties can be designed. Series composition of directional couplers also falls under such an analysis, since X and Y can represent the wave amplitudes in two decoupled arms and $X'Y'$ the resulting amplitudes in the two other arms

GRAPHICAL METHODS

Besides the possibility, already mentioned, of repre- [illegible]nting (17) and (1[illegible] by slide rules, we obtain another [illegible]oup of graphical methods by using any of the standard [illegible]appings of the sphere. A choice of the projection sys-[illegible]m will of course simplify the construction for each [illegible]rticular problem.

We have considered for instance two such projections, [illegible] on the equator of the sphere. The first one, an [illegible]the[illegible]aphic projection is shown in Fig. 7 (Chart O). [illegible], is shown [illegible] a stereographic projection from the pole [illegible] Fig. 8 (Chart S).

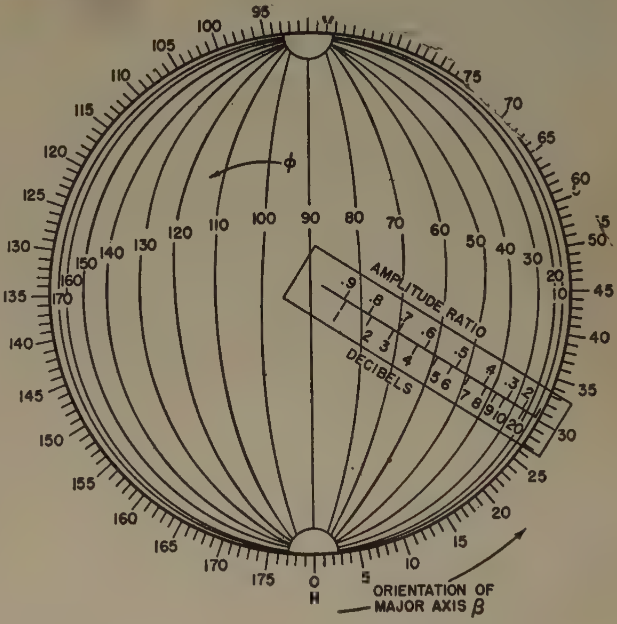

Fig. 7—Orthographic polarization chart (O).

In both cases by drawing the lines along which β and α are constant (meridians and parallels) and the lines along which ϕ and γ, or the ratio $\tan \gamma$, are constant we have a method of direct conversion from any two of these parameters to the others.

Meridians and parallels are radial lines and concentric circles on both charts. They can therefore be represented by means of an alidade carrying a graduation in α. For practical problems the graduation in $\tan \alpha$ or $20 \log \tan \alpha$ (decibels) is sometimes useful.

The lines ϕ constant are circles on Chart S and ellipses on Chart O. The lines γ constant are straight lines

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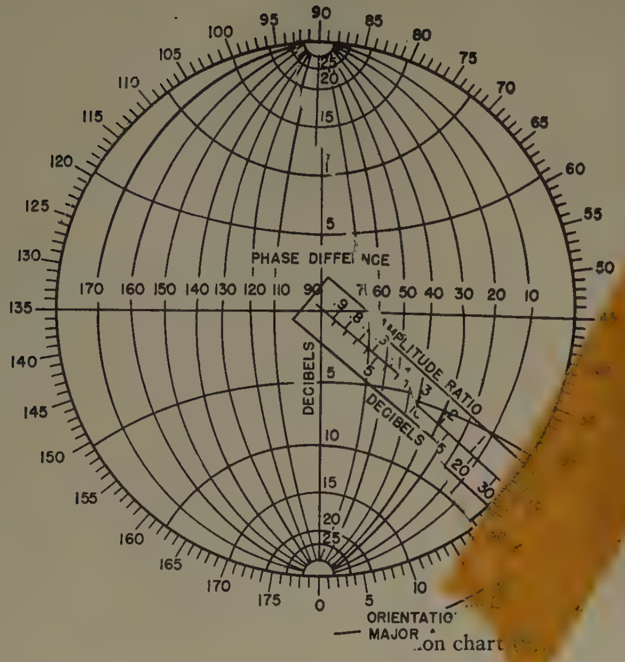
[11] Although currently used in optics since the work of Poincaré, this property does not seem to have been applied to problems of electromagnetism.

[12] H. Weyl, "The Theory of Groups and Quantum Mechanics," p. 144.

[13] A. G. Fox, "An adjustable wave-guide phase changer," PROC. I.R.E., vol. 35, p. 1685–1698; December, 1947.



on chart

Fig. 8—Stereographic po

to HV on Chart O and circles on Chart S. perpendicular sections with HV are obtained from the Their inte

α graduation on the alidades since for $\beta=0$, $\gamma=\alpha$ and for $\beta=\pi/2$, $\gamma=\pi/2)-\alpha$.

For problems of conversion the two charts are comparable: S is easier to prepare since it is made of circles instead of ellipses, it is more accurate near the equato, while O is more accurate near the pole. For other problems, such as the determination of polarization b amplitude comparison, the Chart O is better since the solution is obtained by intersection of straight lin instead of circles.

One should not forget that on Chart O each point represents two polarizations of opposite sign. On Chart we could deal with negative polarizations by extending the circles. It is sometimes easier in that case to look at the chart as a projection made from C instead of C'.

CONCLUSIONS

The application of this representation is not limited to polarization problems. Any time relations between an ellipse and the phases and amplitudes of two components are required the Poincaré sphere is a useful tool. The interpretation of an ellipse on an oscilloscope, the study of the rotation field in an imperfect goniometer and the composition of waves of various directions in direction finding are instances of this.

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rt III—Elliptically Polarized Waves and Antennas*

M. L. KALES†

COMPLEX VECTOR REPRESENTATION OF ELLIPTICALLY POLARIZED FIELDS

A UNIFORM elliptically polarized plane wave may be represented in the form[14]

$$\vec{\mathcal{E}}(t) = \vec{\mathcal{E}} e^{j(\omega t - kz)} \tag{23}$$

where $\vec{\mathcal{E}}$ is a complex vector of the form $\vec{\mathcal{E}}=\vec{E}_r+j\vec{E}_i$, and $\vec{E}_r$ and $\vec{E}_i$ are real vectors perpendicular to the z axis and independent of position and time. Thus a uniform elliptically polarized wave is obtained by the superposition of two uniform linearly polarized plane waves, which are in phase quadrature and which are traveling in the same direction. There is clearly no loss of generality in assuming that the direction of propagation is in the direction of the z axis.

It can readily be shown that the wave $\vec{\mathcal{E}}(t)$ can be expressed in the form

$$\vec{\mathcal{E}}(t) = \vec{\mathcal{E}}' e^{j(\omega t - kz + \delta)}, \tag{24}$$

where $\vec{\mathcal{E}}'=\vec{E}_r'+j\vec{E}_i'$, $\vec{E}_r'\cdot\vec{E}_i'=0$. The angle δ and the vectors $\vec{E}_r'$ and $\vec{E}_i'$ are determined by the equations

$$\tan 2\delta = 2\vec{E}_r\cdot\vec{E}_i/(\vec{E}_r^2 - \vec{E}_i^2),$$

$$\vec{E}_r' = \vec{E}_r \cos\delta + \vec{E}_i \sin\delta,$$

$$\vec{E}_i' = -\vec{E}_r \sin\delta + \vec{E}_i \cos\delta.$$

Equation (24) is the usual representation of an elliptically polarized wave as the sum of two linearly polarized waves which are in both time and space quadrature. At any point in space the terminus of the instantaneous $\vec{E}$ vector describes an ellipse with axes in the directions of $\vec{E}_r'$ and $\vec{E}_i'$. The lengths of the semi-axes are $|\vec{E}_r'|$ and $|\vec{E}_i'|$.

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* Decimal classification: R115.7×R129. Original manuscript received by the Institute, June 30, 1950.

† Naval Research Laboratory, Washington, D. C.

[14] Throughout this paper complex vectors and scalars will be represented by script symbols; real vectors and scalars by printed symbols.

Insofar as the behavior of the instantaneous $\vec{E}$ vector at a fixed point in space is concerned, the preceding discussion applies equally well to an arbitrary vector function of the time which is represented as the real part of the complex vector

$$\vec{\mathcal{U}}(t) = \vec{\mathcal{U}}e^{j\omega t} = (\vec{U}_r + j\vec{U}_i)e^{j\omega t}. \tag{25}$$

It follows that any vector of the form

$$\vec{U} = \mathcal{U}_x \cos(\delta_x + \omega t)\vec{i}_x + U_y \cos(\delta_y + \omega t)\vec{i}_y + U_z \cos(\delta_z + \omega t)\vec{i}_z$$

describes an ellipse, since such a vector may be represented as the real part of a vector of the form (23); i.e.,

$$\vec{U} = Re\,[\{U_x \cos\delta_x\vec{i}_x + U_y \cos\delta_y\vec{i}_y + U_z \cos\delta_z\vec{i}_z\} + j\{U_x \sin\delta_x\vec{i}_x + U_y \sin\delta_y\vec{i}_y + U_z \sin\delta_z\vec{i}_z\}]e^{j\omega t}.$$

If a positive normal is assigned to the plane of the polarization ellipse of $\vec{U}(t)$, the polarization may be defined as right-handed or left-handed according as the vector is rotating clockwise or counterclockwise when viewed by an observer looking in the direction of the normal. In the case of an elliptically polarized plane wave, the positive normal is generally taken in the direction of propagation.

If an arbitrary pair of orthogonal unit vectors $\vec{i}_x$, $\vec{i}_y$ are selected in the plane of $\vec{\mathcal{U}}(t)$, then $\vec{\mathcal{U}}(t)$ may be expressed in the form

$$\vec{\mathcal{U}}(t) = (\mathcal{U}_x\vec{i}_x + \mathcal{U}_y\vec{i}_y)e^{j\omega t}$$

where $\mathcal{U}_x$ and $\mathcal{U}_y$ are complex. If we let $\mathcal{U}_x = |\mathcal{U}_x|e^{j\delta_x}$ and $\mathcal{U}_y = |\mathcal{U}_y|e^{j\delta_y}$, and if the normal $\vec{n}$ is chosen so that the vectors $\vec{i}_x$, $\vec{i}_y$, and $\vec{n}$ form a right-handed system when taken in the indicated order then it is easily shown that the polarization is right-handed or left-handed according as $\sin(\delta_x - \delta_y)$ is positive or negative, or in other words, according as the x component of $\vec{\mathcal{U}}(t)$ leads or lags the y component.

ALGEBRA OF COMPLEX VECTORS

The use of complex vectors in representing elliptically polarized waves suggests the possibility of using a complex vector algebra in studying such waves. An appropriate algebra, which will be used in the subsequent discussion, will now be outlined.

A complex vector is defined as a vector of the form

$$\vec{\mathcal{U}} = \vec{U}_r + j\vec{U}_i,$$

$\vec{U}_r$ and $\vec{U}_i$ being real vectors which in general are not in the same direction. As has been seen, at a given point in space, $\vec{U}(t) = Re(\vec{U}_r + j\vec{U}_i)e^{j\omega t}$ describes an ellipse. The direction of rotation of $\vec{U}(t)$ may be indicated by means of an arrow placed on the ellipse. Such a directed ellipse may be regarded as a geometrical representation of a complex vector. It should be noted that a complex vector is not simply the product of a real vector and a complex scalar. It is clear that this will be true only if $\vec{U}_r$ and $\vec{U}_i$ are in the same direction, in which case $\vec{\mathcal{U}}$ is linearly polarized.

In general, a complex vector determines a plane, namely the plane of $\vec{U}_r$ and $\vec{U}_i$. In the discussion which follows it is assumed that the complex vectors under consideration lie in parallel planes unless otherwise indicated.

The scalar product of two complex vectors, $\vec{\mathcal{U}} = \vec{U}_r + j\vec{U}_i$ and $\vec{U} = \vec{V}_r + j\vec{V}_i$ is defined as

$$\vec{\mathcal{U}} \cdot \vec{U} = (\vec{U}_r \cdot \vec{V}_r - \vec{U}_i \cdot \vec{V}_i) + j(\vec{U}_i \cdot \vec{V}_r + \vec{U}_r \cdot \vec{V}_i).$$

Their vector product is defined as

$$\vec{\mathcal{U}} \times \vec{U} = (\vec{U}_r \times \vec{V}_r - \vec{U}_i \times \vec{V}_i) + j(\vec{U}_r \times \vec{V}_i + \vec{U}_i \times \vec{V}_r).$$

The magnitude of $\vec{\mathcal{U}}$ is $|\vec{\mathcal{U}}| = \sqrt{\vec{\mathcal{U}} \cdot \vec{\mathcal{U}}^*}$. Two vectors $\vec{\mathcal{U}}$ and $\vec{U}$ are said to be orthogonal if $\vec{\mathcal{U}} \cdot \vec{U}^* = 0$, and parallel if $\vec{\mathcal{U}} \times \vec{U} = 0$.

It is not difficult to show that the conditions of orthogonality and parallelism are equivalent respectively to the two relations $\vec{U} = K_1\vec{\mathcal{U}}^* \times \vec{n}$ and $\vec{U} = K_2\vec{\mathcal{U}}$, where the K's are constants. These relations have an interesting geometrical interpretation. As we have seen, the vector $\vec{\mathcal{U}}e^{j\omega t}$ may be expressed in the form $\vec{\mathcal{U}}e^{j\omega t} = (\vec{U}_r + j\vec{U}_i)e^{j(\omega t+\delta)}$, where $\vec{U}_r$ and $\vec{U}_i$ are a pair of orthogonal real vectors in the plane of $\vec{\mathcal{U}}$. From this form, and the criterion for sense of rotation, it is at once evident that the ellipse determined by $\vec{\mathcal{U}}^*e^{j\omega t} = (\vec{U}_r - j\vec{U}_i)e^{(j\omega t-\delta)}$ has the same orientation and axial ratio[15] as that determined by $\vec{\mathcal{U}}e^{j\omega t}$, but has the opposite sense. It is also clear that $\vec{\mathcal{U}}^* \times \vec{n}$ is obtained by rotating $\vec{\mathcal{U}}$ through 90° in the plane of $\vec{\mathcal{U}}$. Thus two complex vectors $\vec{\mathcal{U}}$ and $\vec{U}$ are orthogonal if and only if the ellipses which represent them have the same axial ratio, opposite sense of rotation, and major axes perpendicular. From the relation which expresses the condition of parallelism it is seen that $\vec{\mathcal{U}}$ and $\vec{U}$ are parallel if and only if the ellipses representing them have the same orientation, axial ratio, and sense of rotation.

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[15] The axial ratio referred to in this and the next s[illegible] inverse of the axial ratio referred to in Part II.

RESOLUTION OF ELLIPTICALLY POLARIZED FIELDS INTO ORTHOGONAL ELLIPTICALLY POLARIZED COMPONENTS

If $\vec{\mathcal{E}}$ is an arbitrary complex vector, and if $\vec{u}$ and $\vec{v}$ denote an arbitrary pair of complex, orthogonal unit vectors in the plane of $\vec{\mathcal{E}}$, then $\vec{\mathcal{E}}$ may be represented in the form

$$\begin{aligned}\vec{\mathcal{E}} &= (\vec{\mathcal{E}}\cdot\vec{u}^*)\vec{u} + (\vec{\mathcal{E}}\cdot\vec{v}^*)\vec{v},\\ &= \mathcal{E}_u\vec{u} + \mathcal{E}_v\vec{v}.\end{aligned} \tag{26}$$

From the orthogonality of $\vec{u}$ and $\vec{v}$, it follows that

$$|\vec{\mathcal{E}}|^2 = |\mathcal{E}_u|^2 + |\mathcal{E}_v|^2. \tag{27}$$

From equation (26) we conclude that a given elliptically polarized field can be resolved into two orthogonal elliptically polarized fields in an infinite number of ways. The axial ratio, orientation, and sense of the ellipse representing one of the component fields can be arbitrarily specified, in which case the other component field will be represented by an ellipse having the same axial ratio, opposite sense, and major axis perpendicular to the major axis of the first. Equation (27) states that the power density in an elliptically polarized wave is the sum of the power densities of any two orthogonal elliptically polarized components.

Consider several special cases of (26). If $\vec{u}$ and $\vec{v}$ are real, then the component fields represented by $\mathcal{E}_u\vec{u}$ and $\mathcal{E}_v\vec{v}$ are linearly polarized. As already shown, it is possible to select a pair of real orthogonal unit vectors $\vec{i}_x$, $\vec{i}_y$ such that $\vec{\mathcal{E}}$ takes the form $\vec{\mathcal{E}}=(E_x\vec{i}_x+jE_y\vec{i}_y)e^{j\delta}$, where E_x and E_y are real. Now let $\vec{u}$ and $\vec{v}$ be a pair of real unit vectors making an angle θ with $\vec{i}_x$ and $\vec{i}_y$, respectively. Then

$$\mathcal{E}_u = (E_x\cos\psi + jE_y\sin\psi)e^{j\delta};$$
$$\mathcal{E}_v = (-E_x\sin\psi + jE_y\cos\psi)e^{j\delta}.$$

If ψ is chosen so that $|\mathcal{E}_u|^2=|\mathcal{E}_v|^2$, then

$$(E_x^2-E_y^2)\cos 2\psi = 0.$$

Thus $|\mathcal{E}_u|=|\mathcal{E}_v|$ if $\psi=\pi/4$, or $3\pi/4$.

From the above results we conclude that an elliptically polarized field of arbitrary axial ratio and sense of rotation can be produced by superimposing two orthogonal linearly polarized fields for which either (a) the two components are in phase quadrature and the amplitudes are properly chosen, or (b) the two components are equal in amplitude and the phase is properly chosen. In the first case the axes of the ellipse will be in the directions of the two components which are in phase quadrature, and in the second case the axes of the ellipse will bisect the angles between the two components of equal amplitude.

[illegible] solution of an elliptically polarized field into [illegible] left-handed circularly polarized components is of considerable importance. Let $\vec{\mathcal{E}}$ be represented in the form

$$\vec{\mathcal{E}} = \mathcal{E}_x\vec{i}_x + \mathcal{E}_y\vec{i}_y \tag{28}$$

where $\vec{i}_x$ and $\vec{i}_y$ are an arbitrary pair of real orthogonal unit vectors in the plane of $\vec{\mathcal{E}}$, which together with the normal $\vec{n}$ form a right-handed system. A pair of right- and left-handed circularly polarized unit vectors may be selected as

$$\vec{u}_R = \frac{1}{\sqrt{2}}(\vec{i}_x - j\vec{i}_y); \qquad \vec{u}_L = \frac{1}{\sqrt{2}}(\vec{i}_x + j\vec{i}_y).$$

Applying (26), (28) may be written

$$\begin{aligned}\vec{\mathcal{E}} &= \tfrac{1}{2}(\mathcal{E}_x + j\mathcal{E}_y)(\vec{i}_x - j\vec{i}_y) + \tfrac{1}{2}(\mathcal{E}_x - j\mathcal{E}_y)(\vec{i}_x + j\vec{i}_y)\\ &= \mathcal{E}_R\vec{u}_R + \mathcal{E}_L\vec{u}_L.\end{aligned} \tag{29}$$

From the discussion of the conditions for orthogonality and parallelism, it is evident that a pair of right- and left-handed circularly polarized vectors are always orthogonal and two circularly polarized vectors of the same senses are parallel, provided the same unit normal $\vec{n}$ is used in determining the sense of polarization. Hence if $\vec{u}_R'$ and $\vec{u}_L'$ denote any other pair of right- and left-handed circularly polarized unit vectors, then $\vec{u}_R'=\vec{u}_Re^{j\delta}$ and $\vec{u}_L'=\vec{u}_Le^{j\delta}$. From (26) we see that

$$\vec{\mathcal{E}} = (\vec{\mathcal{E}}\cdot\vec{u}_R'^*)\vec{u}_R' + (\vec{\mathcal{E}}\cdot\vec{u}_L'^*)\vec{u}_L'.$$

But

$$(\vec{\mathcal{E}}\cdot\vec{u}_R'^*)\vec{u}_R' = (\vec{\mathcal{E}}\cdot\vec{u}_R^*e^{-j\delta})e^{j\delta}\vec{u}_R = (\vec{\mathcal{E}}\cdot\vec{u}_R^*)\vec{u}_R,$$

and similarly

$$(\vec{\mathcal{E}}\cdot\vec{u}_L'^*)\vec{u}_L' = (\vec{\mathcal{E}}\cdot\vec{u}_L^*)\vec{u}_L.$$

Thus the component vectors on the right of (29) are independent of the particular choice of right- and left-handed circularly polarized unit vectors, or in other words, the resolution into right- and left-handed circularly polarized fields is unique. It is clear also that $|\mathcal{E}_R'|=|\mathcal{E}_R|$ and $|\mathcal{E}_L'|=|\mathcal{E}_L|$.

Since the vectors which are the real parts of $\mathcal{E}_R\vec{u}_Re^{j\omega t}$ and $\mathcal{E}_L\vec{u}_Le^{j\omega t}$ rotate in opposite directions with constant magnitudes $|\mathcal{E}_R|$ and $|\mathcal{E}_L|$, it is seen at once that $|\vec{E}|_{\max}=|\mathcal{E}_R|+|\mathcal{E}_L|$ and $|E|_{\min}=\big||\mathcal{E}_R|-|\mathcal{E}_L|\big|$. Hence the axial ratio r is given by

$$r = \left|\frac{|\mathcal{E}_R|+|\mathcal{E}_L|}{|\mathcal{E}_R|-|\mathcal{E}_L|}\right|. \tag{30}$$

It is easy to show that $\vec{\mathcal{E}}$ is right- or left-handed according as $|\mathcal{E}_R|$ is greater or less than $|\mathcal{E}_L|$.

SIGNIFICANCE OF THE TERM "PHASE" APPLIED TO ELLIPTICALLY POLARIZED FIELDS

The term "phase" was defined originally in connection with scalar quantities, but requires further definition for use with vector quantities. One method is to consider the phase of the components of a vector field, since the components are scalar quantities. This would make the phase dependent on the co-ordinate system, which is generally undesirable. Another approach is to refer the field at each point in space to a unit vector in the direction of the field. Thus if $\vec{u}$ is a unit vector in the direction of $\vec{\mathcal{E}}$, and we write $\vec{\mathcal{E}}=\mathcal{E}_u\vec{u}$, then the phase of $\vec{\mathcal{E}}$ may be defined as the argument of the complex amplitude $\mathcal{E}_u$.

In the case of linearly polarized fields, if the suggested definition of phase is employed, there will be an ambiguity of 180° in the determination of the phase, which must be resolved by some other means. For if $\vec{u}$ is a real unit vector in the direction of $\vec{E}$, then so is $-\vec{u}$. In the case of elliptically polarized fields, the ambiguity is even greater. For if $\vec{u}$ is any complex unit vector, then $\vec{u}'=e^{j\delta}\vec{u}$ is parallel to $\vec{u}$ for an arbitrary δ. This means that the phase of $\vec{\mathcal{E}}$ can have an infinite number of distinct values, depending on the choice of $\vec{u}$. By a suitable choice of $\vec{u}$ it is possible, however, to reduce the ambiguity to one of 180°. If we let $\vec{i}_x$ and $\vec{i}_y$ be two real unit vectors in the directions of the major and minor axes, respectively, of the ellipse which represents $\vec{\mathcal{E}}$, then a suitable vector $\vec{u}$ may be defined with the aid of a parameter α by the equation

$$\vec{u} = \sin\alpha\vec{i}_x - j\cos\alpha\vec{i}_y. \qquad (31)$$

We can then write $\vec{\mathcal{E}}=|\vec{\mathcal{E}}|ue^{j\delta}$, and define δ to be the phase of $\vec{\mathcal{E}}$. Physically, this definition of phase leads to the result that if two elliptically polarized fields represented by $\vec{\mathcal{E}}_1$ and $\vec{\mathcal{E}}_2$ are in phase, the real vectors $\vec{E}_1$ and $\vec{E}_2$ assume their maximum and minimum lengths at the same instants of time. It should be noted that the definition of phase that has been suggested applies equally well to linearly and elliptically polarized fields. For fields that are circularly polarized, this definition of phase still leads to ambiguous results.

For future reference it may be noted that when $\vec{u}$ is expressed in the form of (31), α can always be chosen in the interval $(\pi/4)\leq\alpha\leq(3\pi/4)$, and $r=|\tan\alpha|$. If $\vec{i}_x, \vec{i}_y, \vec{n}$ form a right-handed system, then $\vec{u}$ is right- or left-hand polarized, according as α is in the first or second quadrant.

RELATIONS USEFUL IN MEASUREMENTS

Let us assume that a dipole is rotated in the plane of polarization of an elliptically polarized field. Let a pair of orthogonal real unit vectors $\vec{i}_x$ and $\vec{i}_y$ be chosen arbitrarily in this plane. Then by a proper choice of the origin of time $\vec{\mathcal{E}}$ may be expressed in the form $\vec{\mathcal{E}}=E_xe^{j\delta}\vec{i}_x+E_y\vec{i}_y$, where E_x and E_y are positive. Let the dipole make an angle ψ with $\vec{i}_x$, then the component of $\vec{\mathcal{E}}$ in the direction of the dipole is $\mathcal{E}_\psi=E_xe^{j\delta}\cos\psi+E_y\sin\psi$. The power received by the dipole is proportional to

$$|\mathcal{E}_\psi|^2 = \tfrac{1}{2}[E_x^2+E_y^2+\{(E_x^2+E_y^2)^2 - 4E_x^2E_y^2\sin^2\delta\}^{1/2}\cos 2(\psi-\beta)], \qquad (32)$$

where $\tan 2\beta=2E_xE_y\cos\delta/(E_x^2-E_y^2)$.

If a parameter η is defined by the relation

$$\sin\eta = |2E_xE_y\sin\delta/(E_x^2+E_y^2)|,$$

then it follows from (32) that

$$r = \frac{|\mathcal{E}_\psi|_{\max}}{|\mathcal{E}_\psi|_{\min}} = \cot(\eta/2). \qquad (33)$$

In the special case where $E_x=E_y$, the formula for r reduces to

$$r = \max\left\{\left|\tan\frac{\delta}{2}\right|, \left|\cot\frac{\delta}{2}\right|\right\}.$$

If $\vec{\mathcal{E}}$ is expressed in the form $\vec{\mathcal{E}}=\vec{E}_r+j\vec{E}_i$, the axial ratio r may be obtained from these same relations simply by replacing E_x and E_y by $|\vec{E}_r|$ and $|\vec{E}_i|$, and letting δ represent the angle between the vectors $\vec{E}_r$ and $\vec{E}_i$.

From (32) it is evident that the angle ψ for which $|\mathcal{E}_\psi|$ is a maximum, satisfies the equation $\tan 2\psi=\tan 2\beta=2E_xE_y\cos\delta/(E_x^2-E_y^2)$. In order for $|\mathcal{E}_\psi|$ to be a maximum, ψ must be chosen so that one of the two inequalities $(E_x^2-E_y^2)\cos 2\psi>0$, $E_xE_y\cos\delta\sin 2\psi>0$ is satisfied. These relations determine the angle ψ which the major axis of the ellipse makes with $\vec{i}_x$. In the event that $E_x^2=E_y^2$ and $\cos\delta=0$, then the field is circularly polarized and $|\mathcal{E}_\psi|$ is constant. If (32) is plotted in polar co-ordinates, a dumbbell-shaped curve is obtained which represents the power received by the dipole as a function of the angle or orientation ψ. This curve is called a polarization pattern.

RELATIONS INVOLVING TRANSMITTING AND RECEIVING ANTENNAS

Let us now consider the relation of elliptically polarized fields to antennas. The distant field $\vec{\mathcal{E}}(P,t)$ produced by an antenna can be expressed in the form

$$\vec{\mathcal{E}}(P,t) = \frac{\vec{\mathcal{E}}(\theta,\phi)}{R}e^{j(\omega t-kR)}, \qquad (34)$$

where $\vec{\mathcal{E}}(\theta,\phi)$ is a complex vector, and R, θ, and ϕ are the spherical co-ordinates of the point P. If the factor $1/R$ is omitted, the variation of the remaining factor along a radius is identical with that of an elliptically polarized plane wave traveling in the (θ, ϕ) direction. It is convenient to introduce a complex unit vector $\vec{p}=\vec{p}(\theta, \phi)$ defined by the relation

$$\vec{p}(\theta, \phi) = \vec{\mathcal{E}}(\theta, \phi)/|\vec{\mathcal{E}}(\theta, \phi)|. \qquad (35)$$

From the foregoing discussion it is clear that $\vec{p}$ completely describes the state of polarization of the field, that is, the axial ratio, sense, and orientation of the ellipse which represents the instantaneous $\vec{E}$ vector. For this reason $\vec{p}$ shall be referred to as the *polarization unit vector.*

Another vector which will be useful in describing the transmitted field of an antenna is

$$\vec{g}(\theta, \phi) = \sqrt{G(\theta, \phi)}\;\vec{p}(\theta, \phi)$$

$$= (2\pi\sqrt{\epsilon/\mu}/P_t)^{1/2}|\vec{\mathcal{E}}(\theta, \phi)|\,\vec{p}(\theta, \phi), \qquad (36)$$

where $G(\theta, \phi)$ is the power gain of the antenna in the direction (θ, ϕ), and P_t is the transmitted power. This vector will be referred to as the *transmission vector* of the antenna. The significance of $\vec{g}$ becomes apparent when, with the aid of (35) and (36), (34) is rewritten in the form

$$\vec{\mathcal{E}}(P, t) = (\sqrt{\mu/\epsilon}/2\pi)^{1/2}\sqrt{P_t}\;\vec{g}\,\frac{e^{j(\omega t-kR)}}{R}. \qquad (37)$$

Since for a lossless antenna $\sqrt{P_t}$ is proportional to the voltage at the input terminals of the antenna, it is seen that the transmission vector may be used to express the radiation field of an antenna in terms of the input voltage in much the same way that the gain may be used to express the power per unit solid angle in a given direction in terms of the power delivered to the antenna. It follows immediately from the definition of $\vec{g}$ that

$$|\vec{g}(\theta, \phi)|^2 = G(\theta, \phi). \qquad (38)$$

By analogy with the case of linearly polarized antennas, we shall also define a vector $\vec{\rho}=\vec{\rho}(\theta, \phi)$ by the relation

$$\vec{\rho}(\theta, \phi) = (\lambda/\sqrt{4\pi})\,\vec{g}^{*}(\theta, \phi). \qquad (39)$$

This vector will be referred to as the *reception vector* of the antenna. If we denote by $A=A(\theta, \phi)$ the receiving cross section of the antenna, then we see from (39) that

$$|\vec{\rho}(\theta, \phi)|^2 = \lambda^2/4\pi G(\theta, \phi) = A(\theta, \phi). \qquad (40)$$

If an antenna receives power from an incident elliptically polarized plane wave $\vec{\mathcal{E}}(t)=\vec{\mathcal{E}}e^{j\omega t}$, then the complex received voltage is given by $U=K\vec{\mathcal{E}}\cdot\vec{\rho}^{*}$.[16] If the receiver is matched to the line which has an impedance Z_0, and if the reflection coefficient presented to the line by the antenna is Γ, then $|K|=\{Z_0(1-|\Gamma|^2)\sqrt{\epsilon/u}\}^{\frac{1}{2}}$. The power received by the antenna is given by

$$P_r = |U|^2/2Z_0 = (1-|\Gamma|^2)\tfrac{1}{2}\sqrt{\epsilon/\mu}\,(\vec{\mathcal{E}}\cdot\vec{\rho}^{*})^2.$$

If both the receiver and antenna are matched to the line, then $P_r=\frac{1}{2}\sqrt{\epsilon/u}|\vec{\mathcal{E}}\cdot\vec{\rho}^{*}|.^2$

Let $\vec{p}$ be the polarization unit vector of the incident field $\vec{\mathcal{E}}$, and let $\vec{q}$ be the unit vector $\vec{\rho}/|\vec{\rho}|$. (Note that $\vec{q}$ is the conjugate of the polarization unit vector of the receiving antenna when the antenna is used to transmit). Then the expression for P_r takes the form

$$P_r = \tfrac{1}{2}\sqrt{\epsilon/\mu}|\vec{\mathcal{E}}|^2|\vec{\rho}|^2|\vec{p}\cdot\vec{q}^{*}|^2.$$

As is the case with real vectors, the magnitude of the scalar product of two unit complex vectors cannot exceed unity. The factor $|\vec{p}\cdot\vec{q}^{*}|^2$ will be called the *polarization efficiency* and will be denoted by f. The factor $\frac{1}{2}\sqrt{\epsilon/u}|\vec{\mathcal{E}}|^2$ represents the power per unit area in the incident field and will be denoted by S. Substituting in the formula for P_r and remembering that $|\vec{\rho}|^2=A$, we obtain the formula

$$P_r = SAf. \qquad (41)$$

In the case where the incident and transmitted fields are both linearly polarized, the factor f is given by $f=\cos^2\psi$, where ψ is the angle between the incident and transmitted $\vec{E}$ vectors. When $\psi=0$, (41) reduces to the well-known formula for the maximum power received by a linearly polarized antenna, $(P_r)_{\max}=SA$.

The relations above make it possible to define the polarization efficiency in physical terms. The polarization efficiency is the ratio of the power received from an incident field in a given state of polarization to the power received when the polarization of the incident field is adjusted for maximum power received, the power density in the incident field being held constant.

It is interesting to consider the foregoing relations explicitly in terms of the polarization parameters which describe the incident field and the receiving antennas. It follows from (39) that the vectors which represent $Re(\vec{\rho}e^{j\omega t})$ and $Re(\vec{g}e^{j\omega t})$ are rotating in opposite directions when viewed from the same point, and that the ellipses described by these vectors have the same ellipticity and orientation. However, if the positive normal to the plane of $\vec{\rho}$ points toward the antenna, and the positive normal to the plane of $\vec{g}$ points away from the antenna, then the sense of polarization of the two vectors $Re(\vec{\rho}e^{j(\omega t+kR)})$ and $Re(\vec{g}e^{j(\omega t-kR)})$ will be the same. In other words, the sense of polarization of $Re(\vec{\rho}e^{j(\omega t+kR)})$ is the same as that of the field which would be transmitted by the receiving antenna in the given direction.

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[16] M. L. Kales and J. I. Bohnert, "Elliptically polarized waves and antennas," NRL Report No. 3686.

The vector $\vec{\mathcal{E}}$ lies in a plane perpendicular to the (θ, ϕ) direction. In this plane a pair of orthogonal unit vectors $\vec{i}_x$, $\vec{i}_y$ may be chosen so that $\vec{\mathcal{E}}$ takes the form

$$\vec{\mathcal{E}} = |\vec{\mathcal{E}}|\, e^{j\delta_i}(\vec{i}_x \sin \alpha_i - j\vec{i}_y \cos \alpha_i),$$

and another pair of orthogonal unit vectors $\vec{i}_x{}'$, $\vec{i}_y{}'$ may be chosen so that $\vec{\rho}$ takes the form

$$\vec{\rho} = |\vec{\rho}|\, e^{j\delta_t}(\vec{i}_{x'} \sin \alpha_t - j\vec{i}_{y'} \cos \alpha_t).$$

The axial ratios of $\vec{\mathcal{E}}$ and $\vec{\rho}$, are given by $r_i = |\tan \alpha_i|$ and $r_t = |\tan \alpha_t|$, respectively, where

$$\frac{\pi}{4} \leqq \begin{matrix}\alpha_i\\ \alpha_t\end{matrix} \leqq \frac{3\pi}{4}.$$

Using the above expressions for $\vec{\mathcal{E}}$ and $\vec{\rho}$, we find after some manipulation that

$$|\vec{\mathcal{E}} \cdot \vec{\rho}^{\,*}|^2 = |\vec{\mathcal{E}}|^2 |\vec{\rho}|^2 f$$

where f is the polarization efficiency, given by

$$f = \tfrac{1}{2}(1 + \sin 2\alpha_i \sin 2\alpha_t + \cos 2\alpha_i \cos 2\alpha_t \cos 2\psi), \qquad (42)$$

and ψ is the angle between $\vec{i}_x{}'$, and $\vec{i}_x$. In terms of the axial ratios r_i and r_t of the incident and transmitted fields f is given by

$$f = \tfrac{1}{2}\{(1 + r_i^2)(1 + r_t^2) \pm 4r_i r_t + (1 - r_i^2)(1 - r_t^2) \cos 2\psi\}/2(1 + r_i^2)(1 + r_t^2), \qquad (43)$$

where the + or − sign is to be used according as the two fields have the same or opposite sense of polarization.

If the receiving antenna is rotated about an axis in the (θ, ϕ) direction, then only the angle ψ will vary, and the relative maximum and minimum values of f are attained when $\psi = 0$ and $\pi/2$, respectively, in (42). We thus find that

$$\begin{aligned} f_{\max} &= \cos^2(\alpha_i - \alpha_t) \\ f_{\min} &= \sin^2(\alpha_i + \alpha_t). \end{aligned} \qquad (44)$$

If these results are interpreted in terms of the states of polarization of the incident field and of the field which would be transmitted by the receiving antenna in the given direction, it is seen that only the relative orientation of the ellipses representing the two fields is varied, and that f assumes its relative maximum and minimum values when the major axes of the two ellipses are parallel and perpendicular, respectively.

If sense of polarization is considered in addition to variable ψ, then both $f_{\max}$ and $f_{\min}$ of (44) will have two values, the greater or lesser value according as the two senses of polarization are the same or opposite, respectively.

Finally, if the orientation of the ellipses, the axial ratio, and the sense of polarization are all allowed to vary, f will have an absolute maximum value of unity when the major axes are parallel, the axial ratios are equal, and the polarizations are of the same sense; and f will have a minimum value of 0 when the major axes are orthogonal, the axial ratios are equal and the polarizations are of the opposite sense. This last case may be expressed very simply in vector language: the polarization efficiency f has an absolute maximum value of unity when $\vec{\mathcal{E}}$ is parallel to $\vec{\rho}$, and a minimum value of 0 when $\vec{\mathcal{E}}$ is orthogonal to $\vec{\rho}$. It follows that if the incident field is resolved into two complex vector components, one of which is parallel to $\vec{\rho}$ and the other orthogonal to $\vec{\rho}$, all the power received by the antenna will be extracted from the parallel component, the orthogonal component being completely rejected. In the case of linearly polarized fields, when a particular direction of polarization is of interest, a component of the field which is orthogonal to this direction is said to be a *cross-polarized component.* It is clear that this notion may be extended to elliptically polarized fields, two elliptically polarized components being regarded as cross-polarized if they are orthogonal.

Part IV—Measurements on Elliptically Polarized Antennas*

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TO OBTAIN a complete description of the radiation characteristics of an elliptically polarized antenna, it is necessary to measure not only the distribution of radiation intensity as a function of direction, but also the polarization characteristics as well. Two methods for measuring polarization characteristics are outlined in the following paragraphs: one method employs a rotating linearly polarized antenna; the other employs two circularly polarized antennas.

ROTATING LINEARLY POLARIZED ANTENNA

An obvious way to make measurements on an elliptically polarized radiation pattern is to explore the far field with a small linearly polarized receiving antenna. That is, for each considered direction (θ, ϕ), the power received is measured as a function of the orientation of the receiving antenna as it is rotated in the plane normal to the direction of propagation. In order to reduce the labor involved, a special mount and associated circuitry were built. This equipment is shown in operating condition in Fig. 9. The antenna under test is used for transmitting, and the values of θ and ϕ are controlled there. The receiving antenna, usually a small horn, is fastened on the special mount so that the axis of its main lobe, the axis of rotation of the horn, and the line of sight between the two antennas are coincident. The received signal is displayed on a PPI scope or on a meter. For qualitative measurements the horn is rotated rapidly enough to allow the display of the signal on the scope. The face of the scope may be fitted with a specially calibrated transparent chart for the measurement of the axial ratio r and the orientation angle ψ of the major axis of the polarization ellipse. Photographs of power polarization patterns on the scope for linear, elliptical, and circular polarizations are shown in Fig. 10 (a), (b), and (c). For more accurate work, the rotation is made slow enough to permit a meter to follow the signal as detected. It is then necessary to record only the ratio of the maximum signal to the minimum signal, and the value of ψ.

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† Naval Research Laboratory, Washington, D. C.

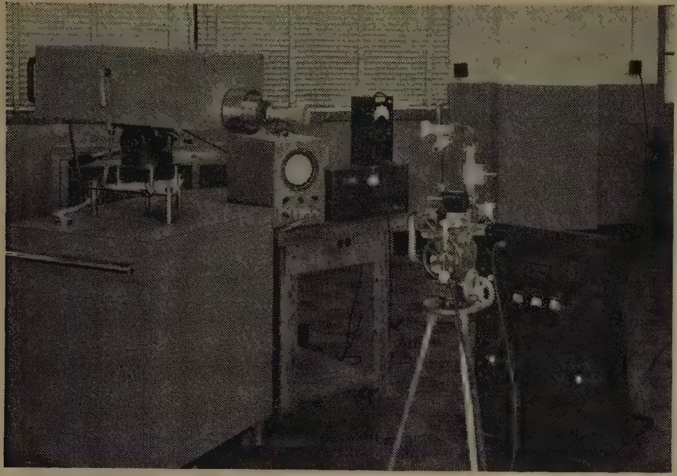
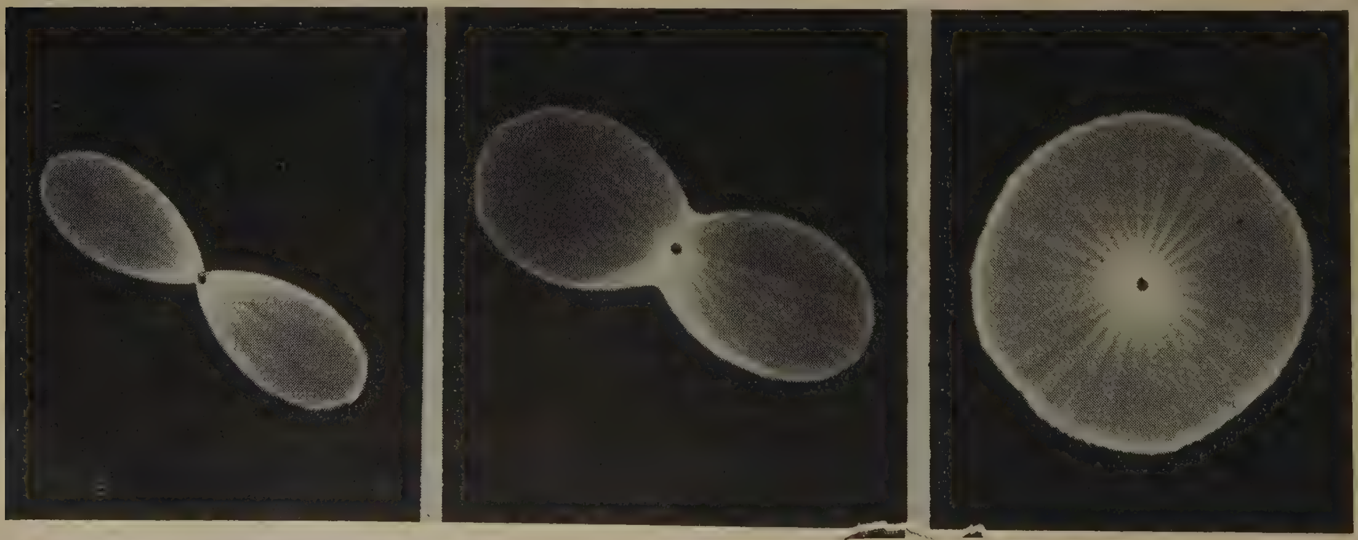


Fig. 9—Automatic equipment for the measurement of polarization patterns.

Two Circularly Polarized Antennas

The second method utilizes the fact that an elliptically polarized field can be represented by two circularly polarized components of opposite sense of polarization. The antenna under test is transmitting, as before. Two circularly polarized antennas are used for receiving, and are assumed identical in their impedance and pattern characteristics except for sense of polarization. If the same receiver with a square law detector is used with both antennas, the received signals are proportional to the square of the quantities $|\mathcal{E}_R|$ and $|\mathcal{E}_L|$[17] which appear in (30). The axial ratio may then be calculated from this equation. The sense of polarization will be right- or left-handed, according as $|\mathcal{E}_R|$ is greater or less than $|\mathcal{E}_L|$.

For many applications, the two circularly polarized antennas could be two helices[18,19] wound in opposite senses. If desired, a single antenna[20] with two pairs of terminals for measuring the right- and left-hand circular components of the incident field may be used.



(a) (b) (c)

Fig. 10—Photographs of power polarization patterns on the scope for (a) linear polarization; (b) elliptical polarization; and (c) circular polarization.

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[17] The symbols used in Part IV are the same as those of Part III.

[18] A. E. Marston and M. D. Adcock, "Radiation from Helices," NRL Report 3634.

[19] J. D. Kraus and J. C. Williamson, "Characteristic's of helical antennas radiating in the axial mode," *Jour. Appl. Phys.*, vol. 19, p. 87; January, 1948.

[20] H. N. Chait, "An Arbitrarily Polarized Antenna for Use on X-band," NRL Report R-3416.

COMPARISON OF THE TWO METHODS

The two methods do not yield directly the same information, since the first does not give the sense of polarization, while the second does not give the orientation angle ψ. With suitable modifications, either method may be made to yield all the required information, but these techniques will not be discussed here.

From patterns of the test antenna obtained by receiving separately on each of the two circularly polarized antennas, one may easily calculate not only the axial ratio, but also the radiation intensity as a function of direction. In general, however, it is much simpler to obtain the single linearly polarized antenna than to obtain the pair of right- and left-hand circularly polarized antennas. Moreover, as will be shown in the following paragraphs, measurements of axial ratio with a linearly polarized antenna will, in general, be more accurate than measurements with a pair of circularly polarized antennas. Thus, for accuracy and for simplicity of instrumentation, the first method employing a linearly polarized antenna is preferable; for ease in obtaining ellipticity and radiation intensity as a function of direction, the second method is preferable, provided the accuracy obtainable is sufficient.

In order to compare the accuracy of the two methods for measuring axial ratio, the following assumptions are made: (1) the existence of a cross-polarized component in the receiving antennas, taken successively to be a maximum of either 25 db, 30 db, or 40 db below the desired component; (2) a difference in antenna gain between the two "circularly" polarized antennas of at most 0.3 db; and (3) errors in meter reading of at most 0.1 db.

Details of the derivation of the formulas for errors in the measured value of axial ratio are omitted, but the results are shown in Fig. 11. The axial ratio as calculated from measurements is referenced on the horizontal scales. The maximum deviations of the true value of the axial ratio from a measured value, resulting from the three types of errors assumed above, are referenced on the vertical scales. The parameter for the two sets of curves is the db difference between the desired component and the cross-polarized component, referenced in Fig. 11 as ρ. These values of the parameter are realistic, since the small horn and the two helices used as the receiving antennas in the two methods possessed cross-polarized components about 30 db down from the desired components.

To illustrate the use of the graph, let us assume that $\rho = 30$ db and that a value of $r = 3$ db is calculated from measurements on the test antenna. Then it is seen from Fig. 11 that the true value of r lies between 2.6 db and 3.4 db if linear components are used, and between 2.3 db and 3.8 db if circular components are used. It is obvious that linear components give more accurate results than circular components for all values of r plotted, admitting [illegible]rors assumed above.

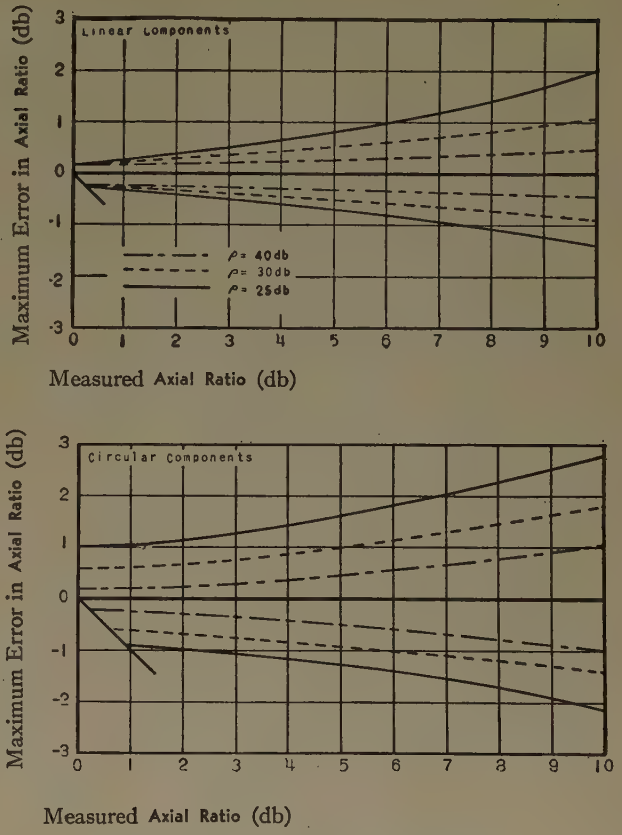

Fig. 11—Errors in measured axial ratio.

MEASUREMENT OF GAIN

The distant field $\vec{\mathcal{E}}(P, t)$ of any antenna is given by (37). Denoting by $\mathcal{E}_u$ and g_u the components of $\vec{\mathcal{E}}$ and $\vec{g}$ in the direction of an arbitrary complex unit vector $\vec{u}$, it follows from (37) that

$$|\mathcal{E}_u|^2 = \sqrt{u/\epsilon}\, P_t |g_u|^2/2\pi R^2.$$

Let $P_u(\theta, \phi) = \frac{1}{2}\sqrt{\epsilon/u}R^2|\mathcal{E}_u|^2$ and $G_u(\theta, \phi) = 4\pi P_u(\theta, \phi)/P_t$ denote respectively the power per unit solid angle and the gain associated with the component $\mathcal{E}_u$. Hence

$$|g_u|^2 = 4\pi P_u(\theta, \phi)/P_t = G_u(\theta, \phi).$$

If a complex unit vector $\vec{v}$ is chosen so that $\vec{u}$ and $\vec{v}$ are orthogonal, then as in Part III,

$$|\vec{g}|^2 = |g_u|^2 + |g_v|^2.$$

By (38), $|\vec{g}|^2 = G(\theta, \phi)$, where $G(\theta, \phi)$ is the power gain relative to an isotropic radiator in the direction (θ, ϕ). Hence

$$G(\theta, \phi) = G_u(\theta, \phi) + G_v(\theta, \phi), \tag{45}$$

and it is seen that the gain $G(\theta, \phi)$ is the sum of the gains of any two orthogonal components. Equation (45) may also be expressed in the form

$$G(\theta, \phi) = 4\pi\{P_u(\theta, \phi) + P_v(\theta, \phi)\}/P_t = 4\pi P(\theta, \phi)/P_t.$$

DEFINITION OF BEAMWIDTH

When considering elliptically polarized antennas, one may be interested not only in the patterns howing the "total" power per unit solid angle, but also in patterns showing power per unit solid angle associated with a particular component. To any one of these patterns, the term "beamwidth" may be applied in the usual way. In general, of course, both the patterns and beamwidths will differ from component to component. Therefore, in speaking of "the" beamwidth of an elliptically polarized antenna, one should indicate clearly which pattern is referred to.

MEASUREMENT OF POWER TRANSFER

The equation for the power transfer between two elliptically polarized antennas can be obtained from (41). This relation can be expressed in terms of measurable quantities by use of (37), (40), and (43) and the definition for S, so that

$$P_i = P_t G_t G_i \left(\frac{\lambda}{4\pi R}\right)^2 \{ (1 + r_i^2)(1 + r_t^2) \pm 4 r_i r_t^2 + (1 - r_i^2)(1 - r_t^2) \cos 2\psi \} 2(1 + r_i^2)(1 + r_t^2), \quad (46)$$

where G_t and G_i are the power gain of the transmitting and receiving antennas, respectively. The angle ψ as previously defined is the angle between the major axes of the polarization ellipses of the transmitting and receiving antennas. The sign of the term $4r_i r_t$ is chosen + or − according as the two antennas are polarized in the same or opposite sense.

It is interesting to note that whenever the polarization efficiency is unity, (46) reduces to

$$P_i = P_t G_t G_i \left(\frac{\lambda}{4\pi R}\right)^2.$$

Thus the formula for power transfer is independent of the particular pair of antennas involved, provided the polarizations of the two satisfy the condition for maximum power transfer

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Synthesis and Analysis of Elliptic Polarization Loci in Terms of Space-Quadrature Sinusoidal Components*

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Summary—**The general case of elliptic polarization produced by three mutually perpendicular sinusoidal electromagnetic field components at a point in space is treated. The elliptic locus is specified in terms of the sinusoidal components and conversely the components are specified when the locus is known. The simpler two-component case is solved first.**

INTRODUCTION

IN THE GENERAL CASE at a point in space where a system of mutually orthogonal co-ordinates 1, 2, 3 has been established, any one of the electromagnetic field vectors may have components E_1, E_2, E_3 of the form

$$E_1 = E_1 \sin(\omega t + \gamma_1) \quad (1)$$

$$E_2 = E_2 \sin(\omega t + \gamma_2) \quad (2)$$

$$E_3 = E_3 \sin(\omega t + \gamma_3). \quad (3)$$

Vector addition of these components, as time is allowed to progress, will always yield an elliptic locus with circular or linear loci as limiting cases.

An elliptic locus is completely defined in a plane by the length of the semimajor axis a; the axial ratio of minor to major axes r; the angle β that the major axis makes with a reference axis; and the sense of rotation.

The object of this paper is to specify the locus in terms of the components or to specify the components in terms of the locus. The solution must include a definition of the plane containing the locus.

SOLUTION OF THE TWO-COMPONENT CASE

Vector addition of any two of the components will yield an elliptic locus in the plane containing these two components. To treat this case, write the parametric equations for an ellipse with center at the origin of co-ordinates and axes aligned with the co-ordinate axes, having semimajor axis a, and ax[illegible] ratio r. These are seen to be

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$$X = a \sin \omega t \tag{4}$$

$$Y = ra \cos \omega t, \tag{5}$$

for, by eliminating t, they reduce to the familiar form

$$\left(\frac{X}{a}\right)^2 + \left(\frac{Y}{ra}\right)^2 = 1. \tag{6}$$

The sense of rotation about the ellipse with increasing t can be determined by plotting two or more points and is determined by the sign of r. The angular velocity of the resulting vector is not constant during the cycle but the vector does make one trip around the ellipse per cycle. Constant angular velocity can be obtained only with components whose variation is periodic but nonsinusoidal. This case is not ordinarily of interest.

Now revolve the axes by an angle $-\beta$. Designating the new co-ordinate axes by primes, we then have

$$X' = a \sin \omega t \cos \beta - ra \cos \omega t \sin \beta \tag{7}$$

$$Y' = ra \cos \omega t \cos \beta + a \sin \omega t \sin \beta. \tag{8}$$

It is desired to represent these functions of a, r, and β by functions of the form of (1) and (2). Taking these respectively as $A \sin \omega t$ and $B \sin (\omega t + \delta)$ where $\delta = \gamma_2 - \gamma_1$, and setting (7) and (8) identically equal to these expressions for all values of t, one obtains the following expressions for A, B, and δ in terms of a, r, and β by equating coefficients of the identities:

$$A = a\sqrt{\cos^2 \beta + r^2 \sin^2 \beta} \tag{9}$$

$$B = a\sqrt{\sin^2 \beta + r^2 \cos^2 \beta} \tag{10}$$

$$\delta = \tan^{-1}\left[\frac{2r}{(1 - r^2) \sin 2\beta}\right]. \tag{11}$$

The relations are conveniently plotted by separating the three variables r, β, and δ and setting a equal to unity, yielding

$$B^2 = -A^2 + (r^2 + 1) \tag{12}$$

$$B^2 = (\operatorname{ctn}^2 \beta)A^2 + (1 - \operatorname{ctn}^2 \beta) \tag{13}$$

$$A^2B^2 \sin^2 \delta = A^2 + B^2 - 1. \tag{14}$$

We may then plot three separate families of curves on the A^2, B^2 plane as shown in Fig. 1. The curves of constant r are had by drawing straight lines between corresponding values of r on the top and right sides of the chart. The curves of constant β are had by drawing straight lines from the upper right-hand corner of the chart through the values of β shown on the quarter circle. The curves of constant δ are hyperbolas and are plotted for 5° intervals of δ. Restricting r to positive values, the sign of δ will be determined by the sense of rotation.[1] Clockwise rotation about the elliptic locus, for an observer looking in the negative direction of a third co-ordinate for a right-handed system yields positive δ. In order to retain the same ellipse, but reverse the sense of rotation, it is only necessary to change the sign of δ. β is the angle, measured in a counterclockwise direction from the positive X axis to the major axis of the ellipse when looking in the direction defined above. For ellipses having $\beta > 90°$, one merely uses supplement angles for both δ and β. Having set a equal to unity, the chart is normalized, for it yields values for ellipses having semimajor axes always equal to unity. If one enters the chart through r and β to determine values of A, B, and δ to produce any desired ellipse, he need merely multiply the values of A and B obtained by the desired length of the semimajor axis, δ being unaffected.

To use the chart in the inverse fashion, one may enter with values of A, B, and δ to find r and β. However, inasmuch as the values of A and B at hand ordinarily will not be normalized, one can enter the chart by evaluating B^2/A^2 and drawing a line having this slope through the lower left corner of the chart. The point at which this line intersects the δ curve then determines r and β. The sense of rotation will be determined by the sign of δ as before. The size factor, if desired, is obtained by dividing the actual A (or B) value by the value of A (or B) determined from the chart for this point.

It is sometimes desirable to vary the axial ratio r, keeping the total power, represented by the two components, constant. This condition is enforced by setting $A^2 + B^2 = \text{constant}$ which results in

$$a^2 = \frac{\text{const}}{1 + r^2}. \tag{15}$$

The size factor a must be adjusted as r is allowed to change, requiring that A^2 and B^2, as read from the chart, be multiplied by this value of a^2. If the constant is set equal to two, then the power will be held equal to that of a circle of unit radius ($r = 1$, $a = 1$).[2]

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[1] The following conditions are required for a consistent system: $0 \leq A \leq +1$, $0 \leq B \leq +1$, $0 \leq r \leq +1$, $0° \leq \beta \leq +180°$, $0° \leq \delta \leq +180°$ (clockwise rotation), $-180° \leq \delta \leq 0°$ (counterclockwise rotation). In using (12), (13), and (14) with these limits, A, B, and δ are single valued.

[2] The two-component case has been treated by Max Born, "Optik," Verlag Julius Springer, Berlin, Germany, 1933, and by H. G. Booker, "Some general properties of the magneto-ionic theory," *Proc. Roy. Soc.*, vol. A147, p. 352; November, 1934. These treatments describe the behavior of the polarization phasor obtained by taking the complex quotient of the components. Inherently, this method cannot yield information readily about the actual size of the elliptic locus in terms of the magnitudes of the components, or vice versa, without plotting the locus for each case. The information is required if it is desired, for example, to keep the power constant while varying separately the axial ratio or orientation.

Georges Deschamps has developed a unique presentation of the polarization phasor on the Poincaré sphere described at the 1949 IRE National Convention and published in the paper, H. G. Booker (editor), V. H. Rumsey, G. A. Deschamps, M. L. Kales, and J. I. Bohnert, "Techniques for handling elliptically polarized waves with special reference to antennas," PROC. I.R.E., pp. 533–552; this issue. At the autumn 1949 Joint IRE-URSI Meeting in Washington, D. C., V. H. Rumsey and T. E. Tice described another presentation derivable from Deschamps' results. They also include a treatment of the left- and right-handed circular components. A review of portions of these publications is included in J. D. Kraus's new book "Antennas," McGraw-Hill Book Co., New York, N. Y., 1950. The Federal Telephone and Radio Corporation handbook, "Reference Data for Radio Engineers," 3rd ed., New York, N. Y., 1949, includes a brief presentation on p. 367 of the behavior of the polarization phasor. J. A. Stratton in "Electromagnetic Theory," McGraw-Hill Book Co., New York, N. Y., 1941, gives an equation on p. 280 from which *one* set of the curves in the Federal handbook chart can be plotted.

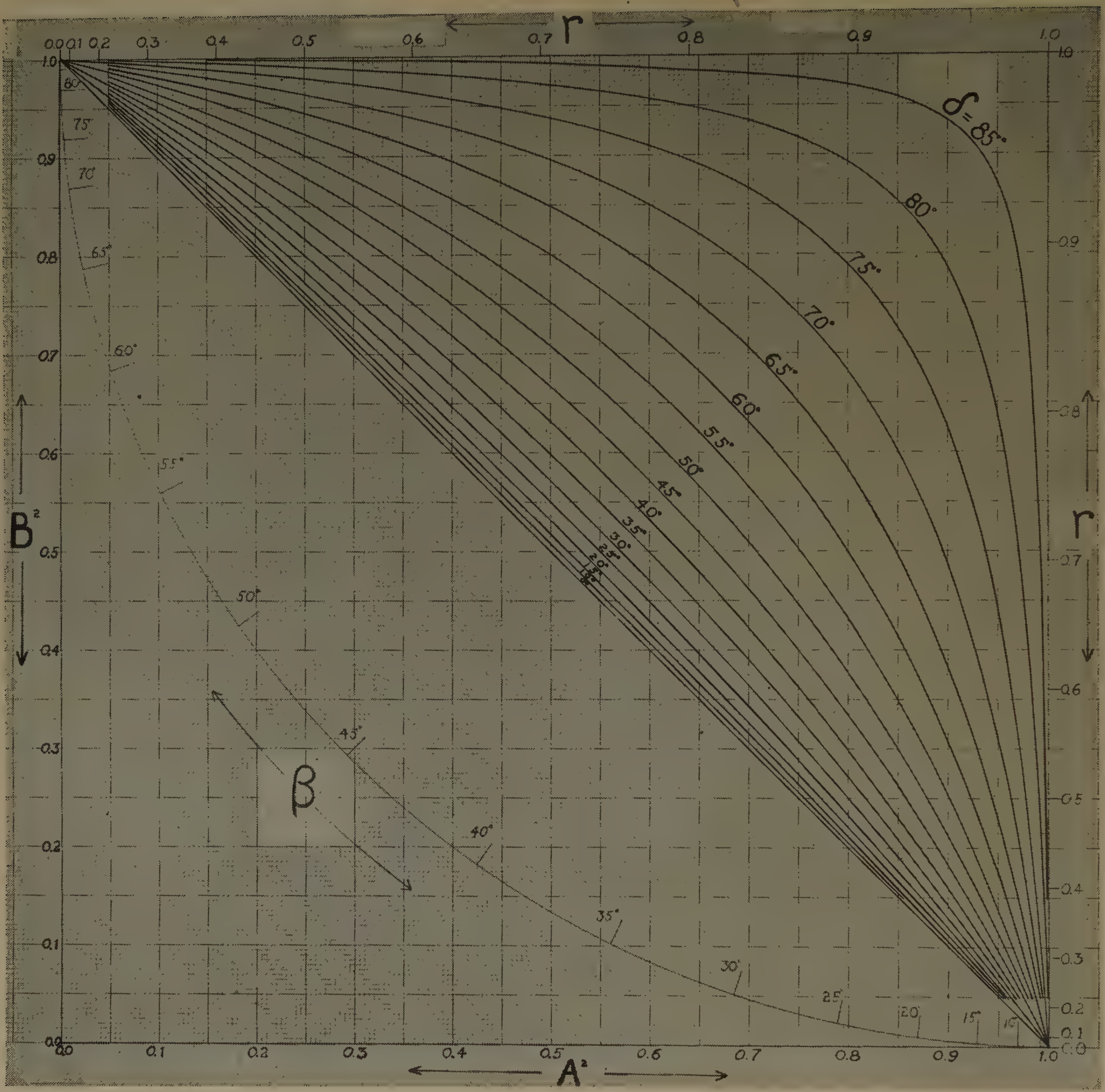

Fig. 1—Normalized chart for determining amplitude and relative phase of two space-quadrature, sine components which will produce any desired elliptic locus. The chart can readily be used in inverse fashion to find the elliptic locus determined by any set of two space-quadrature, sine components.

SOLUTION OF THE THREE-COMPONENT CASE

The three-component case is considerably more complicated because it involves a definition of the plane containing the locus, and this plane is not, in general, one of the co-ordinate planes as it was in the two-component case. Fig. 2 establishes a co-ordinate system 1, 2, 3 and defines angles θ and ϕ of the normal to the plane containing the locus. Further, define orthogonal co-ordinates X, Y in the locus plane such that X is parallel to the 1–2 plane and Y lies in the vertical plane containing the normal to the locus. The positive directions of X and Y are shown in the figure. An auxiliary co-ordinate Y' is defined as Y projected vertically to the 1-2 plane. For convenience in visualization, axes parallel to X and Y have been drawn on the normal to the locus plane at a point above the 1-2 plane. Actually, the X, Y origin is coincident with the 1, 2, 3 origin. Let us first treat the case in which the components of (1), (2), and (3) are given and it is desired to find the locus. Take γ_3 as zero so that E_3 becomes the reference phase. Then γ_1 and γ_2 are the relative phases of E_1 and E_2, respectively. E_1 and E_2 define an elliptic locus in the 1-2 plane, E_2 and E_3 an elliptic locus in the 2-3 plane, and E_3 and E_1 an elliptic locus in the 3-1 plane. These loci are the projections of the actual locus, projected perpendicularly to the co-ordinate planes. When an observer is on the upper side of the 1-2 plane looking toward the 1, 2, 3 origin along the normal to the locus plane, the sense of rotation about these projections will all be the same as that of the actual locus.

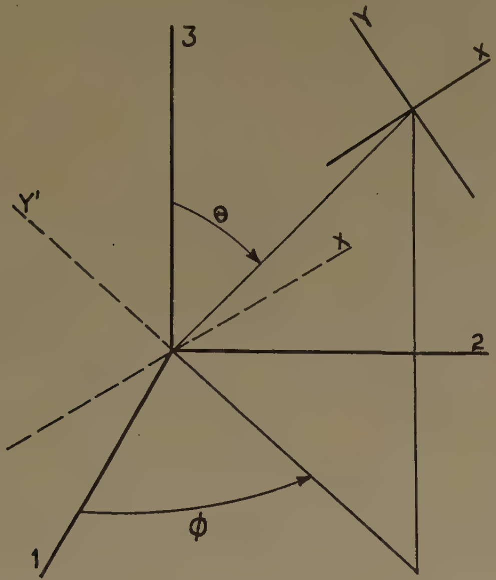

Fig. 2—Co-ordinate system used in the three-component case. The axes 1, 2, 3 are fixed and the X, Y axes lie in the plane of the elliptic locus. The normal to this plane is defined by the angles θ and ϕ. Y' is the vertical projection of Y on the 1-2 plane.

The locus is defined in the X-Y plane by the components

$$E_x = E_x \sin(\omega t - \delta) = aA\underline{/-\delta} \tag{16}$$

$$E_y = E_y \sin \omega t = aB\underline{/0}. \tag{17}$$

E_y is of the reference phase inasmuch as it is in phase with E_3.

From Fig. 2 we may write

$$E_1 = -E_x \sin\phi - E_{y'} \cos\phi \tag{18}$$

$$E_2 = E_x \cos\phi - E_{y'} \sin\phi \tag{19}$$

$$E_3 = E_y \sin\theta \tag{20}$$

where

$$E_{y'} = E_y \cos\theta. \tag{21}$$

Setting the right-hand sides of (18) and (19) equal to those of (1) and (2), respectively, and substituting for E_x, E_y, and E_y' from (16), (17), and (21), identities in t are again obtained. By equating coefficients it can be shown that

$$\tan\phi = -\frac{E_1 \sin\gamma_1}{E_2 \sin\gamma_2}. \tag{22}$$

Hence, if the components of (1), (2), and (3) are given, it is possible to find ϕ directly from (22). This tells one in which quadrant above the 1-2 plane the normal to the locus plane lies except for an ambiguity of 180°. This ambiguity is removed by use of Table I.

In using Table I, take $|\gamma_2-\gamma_1| \leqq 180°$; each combination of signs for γ_1 and γ_2 occurs in two places in the table, but in only one of these places will $\gamma_2-\gamma_1$ have the correct resulting sign.

The sense of rotation about the locus as apparent to an observer above the 1-2 plane looking towards the 1, 2, 3 origin along the normal to the locus plane can now be determined. It is the same as that of the projection in any of the 1, 2, 3 co-ordinate planes when viewed from this position. The sense of any projection is easily determined from the appropriate pair of components and use of Fig. 1. The results are shown in Table I for an observer located as described, taking $\gamma_3=0$.

TABLE I

ϕ	CLOCKWISE	COUNTER-CLOCKWISE
$0 \leqq \phi \leqq 90$	$\gamma_2-\gamma_1>0$ $\gamma_2 \quad <0$ $\gamma_1 \quad >0$	$\gamma_2-\gamma_1<0$ $\gamma_2 \quad >0$ $\gamma_1 \quad <0$
$90 \leqq \phi \leqq 180$	$\gamma_2-\gamma_1>0$ $\gamma_2 \quad >0$ $\gamma_1 \quad >0$	$\gamma_2-\gamma_1<0$ $\gamma_2 \quad <0$ $\gamma_1 \quad <0$
$180 \leqq \phi \leqq 270$	$\gamma_2-\gamma_1>0$ $\gamma_2 \quad >0$ $\gamma_1 \quad <0$	$\gamma_2-\gamma_1<0$ $\gamma_2 \quad <0$ $\gamma_1 \quad >0$
$270 \leqq \phi \leqq 360$	$\gamma_2-\gamma_1>0$ $\gamma_2 \quad <0$ $\gamma_1 \quad <0$	$\gamma_2-\gamma_1<0$ $\gamma_2 \quad >0$ $\gamma_1 \quad >0$

It now remains to find a, r, and β of the actual locus in the X-Y plane. Consider the ellipse in the 1-2 plane defined by $E_1=E_1\underline{/0}$ and $E_2=E_2\underline{/(\gamma_2-\gamma_1)}=E_2\underline{/\delta_{12}}$. This is shown in Fig. 3 where the X, Y' axes are also shown. Subscript 12 is used for values referred to the 1, 2 axes, and subscript xy' for values referred to the X, Y' axes.

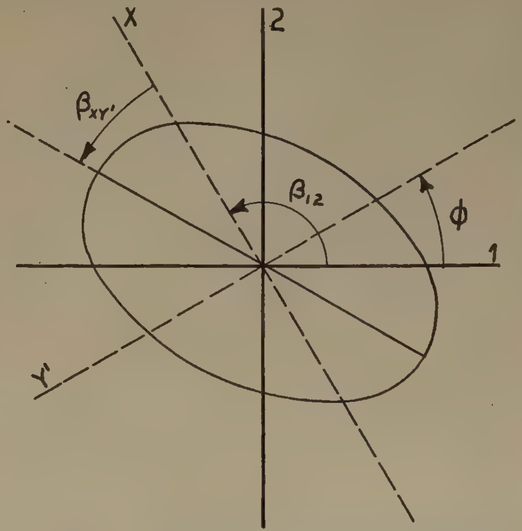

Fig. 3—Projection of the locus in the 1-2 plane showing the X, Y' co-ordinates.

Draw a line on the chart of Fig. 1 having slope E_2^2/E_1^2. At the intersection of this line with $\delta=\delta_{12}=\gamma_2-\gamma_1$, read β_{12} and r_{12}. Also read A_{12} which yields $a_{12}=E_1/A_{12}$. From Fig. 3

$$\beta_{xy'} = \beta_{12} - (90 + \phi). \tag{23}$$

With the value of β_{12} found from Fig. 1 and ϕ from (22), $\beta_{xy'}$ can now be found. This angle should always be taken as positive and less than or equal to 180°. Re-enter Fig. 1 at $r_{xy'} = r_{12}$ and at $\beta_{xy'}$ as determined above and read $B_{xy'}$, $A_{xy'}$, and $\delta_{xy'}$. Since $a_{xy'} = a_{12}$, we now have components in the X-Y' plane

$$E_x = a_{12}A_{xy'}\underline{/0} \tag{24}$$

$$E_{y'} = a_{12}B_{xy'}\underline{/\delta_{xy'}}. \tag{25}$$

Because E_y and $E_{y'}$ are in phase with one another, $\delta_{xy'} = \delta_{xy}$. From inspection of Fig. 2 or (20) and (21)

$$E_y = \sqrt{E_3^2 + E_{y'}^2} \tag{26}$$

$$\tan\theta = \frac{E_3}{E_{y'}}. \tag{27}$$

Inasmuch as $E_{y'} = a_{12}B_{xy'}$ from (25), θ is now determined. E_y is had from (26) and E_x from (24). Entering Fig. 1 again, on a line of slope E_y^2/E_x^2, r_{xy} and β_{xy} are read at the intersection of this line with $\delta = \delta_{xy} = \delta_{xy'}$. The size factor a_{xy} is given by E_y/B_{xy}.

Hence, the locus determined by (1), (2), and (3) is now completely defined in terms of the direction angles θ and ϕ of the normal to the plane containing the locus, and r_{xy}, β_{xy}, and a_{xy} which completely define the shape, orientation, and size of the locus in that plane. The sense or rotation about the locus, when viewed along the normal to the locus plane toward the 1, 2, 3 origin is clockwise for $\delta_{xy} > 0$ and counterclockwise for $\delta_{xy} < 0$. The sense of rotation is also given by Table I.

An alternate method for obtaining (22) has been suggested to the authors. Although it is not particularly simpler, it is more elegant.

By developing (1), (2), and (3) we can write in vector form $\mathbf{E} = \mathbf{U}\sin\omega t + \mathbf{V}\cos\omega t$ with the vectors $\mathbf{U}$ and $\mathbf{V}$ having respective components $E_1\cos\gamma_1$, $E_2\cos\gamma_2$, $E_3\cos\gamma_3$; and $E_1\sin\gamma_1$, $E_2\sin\gamma_2$, $E_3\sin\gamma_3$. Then the locus of the extremity of vector $\mathbf{E}$ is in the plane of $\mathbf{U}$, $\mathbf{V}$ and its sense of rotation from $\mathbf{U}$ to $\mathbf{V}$ is clockwise with respect to the cross product $\mathbf{U}\times\mathbf{V}$. This product has components: $E_2E_3\sin(\gamma_3-\gamma_2)$; $E_3E_1\sin(\gamma_1-\gamma_3)$; $E_1E_2\sin(\gamma_2-\gamma_1)$. This gives angles ϕ and θ

$$\tan\phi = \frac{E_1}{E_2}\,\frac{\sin(\gamma_1-\gamma_3)}{\sin(\gamma_3-\gamma_2)} \tag{22a}$$

$$\tan^2\theta = \frac{E_1^2E_3^2\sin^2(\gamma_1-\gamma_3) + E_2^2E_3^2\sin^2(\gamma_3-\gamma_2)}{E_1^2E_2^2\sin^2(\gamma_2-\gamma_1)}. \tag{27a}$$

By letting γ_3 be zero, (22) and (22a) become identical. Equation (27a) does not particularly simplify the solution for the locus, but is useful as a check by comparison with the result of (27). Furthermore, the sign of each of the components of $\mathbf{U}\times\mathbf{V}$ indicates in which direction each of the three projections of the ellipse is described.

Solution to the inverse problem of finding the three space-quadrature components when the locus is defined is carried out as follows:

Given: a_{xy}, r_{xy}, β_{xy}, θ, ϕ.
To find: E_1, E_2, E_3, γ_1, γ_2.

Step 1. Enter Fig. 1 with r_{xy} and β_{xy}. Obtain A_{xy}, B_{xy}, δ_{xy}.

Then E_x, E_y, $E_{y'}$, and E_3 can be obtained from

$$E_x = a_{xy}A_{xy} \qquad E_{y'} = E_y\cos\theta$$

$$E_y = a_{xy}B_{xy} \qquad E_3 = E_y\sin\theta.$$

Step 2. Enter Fig. 1 at intersection of line of slope $E_{y'}^2/E_x^2$
and $\delta = \delta_{xy'} = \delta_{xy}$. Read $\beta_{xy'}$, $r_{xy'}$, and $B_{xy'}$.
Then $a_{xy'} = E_{y'}/B_{xy'}$.

Step 3. Solving (23) for β_{12}, we obtain

$$\beta_{12} = \beta_{xy'} + (90 + \phi).$$

Step 4. Enter Fig. 1 at $r_{xy'}$ and β_{12} and read A_{12}, B_{12}, δ_{12}. Then

$$E_1 = a_{xy'}A_{12}$$

$$E_2 = a_{xy'}B_{12}$$

$$\gamma_2 - \gamma_1 = \delta_{12}.$$

Step 5. Solve for γ_1 and γ_2 from

$$\sin\gamma_1 = \frac{a_{xy}A_{xy}\sin\phi\sin\delta_{xy}}{E_1}.$$

$$\sin\gamma_2 = \frac{-a_{xy}A_{xy}\cos\phi\sin\delta_{xy}}{E_2}.$$

Hence, E_1, E_2 are obtained from Step 4, E_3 from Step 1, γ_1 and γ_2 from Step 5.

ACKNOWLEDGMENT

The work described in this paper was performed at the Thayer School of Engineering, Dartmouth College, under contract with the Office of Naval Research. The work is also sponsored by the Bureau of Ships. The two-component case is treated more fully in Interim Technical Report No. 1 of February 15, 1949, entitled "Polarization Control of the Incident Wave," prepared under the above-mentioned contract. The notation used here has been altered from that of Interim Technical Report No. 1 so as to conform with that adopted for the group paper, edited by Booker.[3]

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[3] H. G. Booker (editor), V. H. Rumsey, G. A. Deschamps, M. L. Kales, and J. I. Bohnert, "Techniques for handling elliptically polarized waves with special reference to antennas," Proc. I.R.E., pp. 533–552; this issue.

Response Characteristics of Resistance-Reactance Ladder Networks*

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***Summary*—The generalized expressions for the transfer functions for resistance-reactance ladder networks are given and discussed in detail. The output voltage as a function of time is derived when the input voltage is either a unit impulse function or a unit step function. Two methods are discussed for determining the output voltage when the input is any particular function of time.**

INTRODUCTION

IN MANY PRESENT-DAY applications *RC* and *RL* structure are employed where the time constants of all the sections are equal. The transfer function is a convenient parameter in analyzing these circuits. When the input voltage is sinusoidal the output voltage in the steady state is simply given by the product of the root-mean-square value of the input voltage and the transfer function. The principle of superposition can be applied in the case of the steady-state analysis when the input voltage consists of more than one sinusoidal term. The output voltage in the general case can easily be found using some of the elementary principles of the Laplace transform.

The expressions for *RC* and *RL* networks are identical for the low- and high-pass structures considered when expressed in terms of the time constant T, (RC or L/R). Although the development considers specifically *RC* ladder networks, the analysis is directly applicable to *RL* ladder networks as well.

A. Low-Pass RX Ladder Structures

Fig. 1 illustrates the form of the generalized low-pass *RC* ladder network of n sections where $T=RC$ is the time constant of each section (all resistances and capacitances must also be equal).

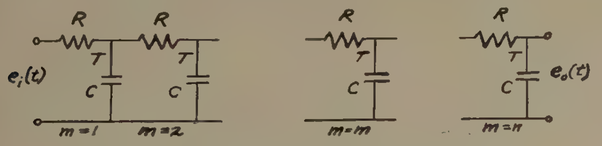

Fig. 1—Generalized low-pass ladder network.

The transfer function in this case can be expressed in the form:[1]

$$\left.\frac{E_o(s)}{E_i(s)}\right]_n = \frac{1}{\sum_{n=0}^{n} a_{m,n}(Ts)^m} \qquad (1)$$

where

$$a_{m,n} = \frac{(m+n)!}{(2m)!(n-m)!} = \binom{n+m}{n-m} \qquad (2)$$

The a's are all binomial coefficients and for any given value of n they lie along a diagonal line of Pascal's triangle.

In order to find the inverse Laplace transform of terms involving the transfer function, it is necessary to separate the denominator of (1) into linear factors so that the Heaviside expansion theorem can be applied. Writing the transfer function in this form,

$$\left.\frac{E_o(s)}{E_i(s)}\right]_n = \frac{1}{\prod_{m=1}^{n}(Ts - b_{m,n})}. \qquad (3)$$

The b's are the roots of the polynomial of degree n which appears in the denominator of (1). In general, these roots are distinct irrational negative real numbers. It can be shown that for any given values of n

$$\prod_{m=1}^{n} b_{m,n} = (-1)^n \quad \text{and} \quad \sum_{m=1}^{n} b_{m,n} = a_{(n-1),n} = 1 - 2n. \qquad (4)$$

The values of the b's are listed in Table I along with their reciprocals for $n \leq 4$.

TABLE I

VALUES OF $b_{m,n}$

n	$b_{m,n}$	$1/b_{m,n}$
1	−1.00000	−1.00000
2	−0.38197 −2.61803	−2.61803 −0.38197
3	−0.19806 −1.55496 −3.24698	−5.04892 −0.64310 −0.30798
4	−0.12061 −1.00000 −2.34730 −3.53209	−8.29091 −1.00000 −0.42602 −0.28312

Response to a unit impulse input voltage: The Laplacian of a unit impulse function[2] $\delta(t)$ is unity. If such an impulse voltage is applied at the input of the *RC* ladder network, the output voltage as a function of time is merely the inverse transform of the transfer function. Using the transfer function in the form of

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[1] Equations (1) and (2) were derived by the author during the summer of 1949, but have been published in the article by E. W. Pschudi, "Admittance and transfer function for an n-mesh *RC* filter network," PROC. I.R.E., vol. 38, pp. 309–310; March, 1950. This paper derives the input admittance and transfer function only for the low-pass case.

[2] The unit impulse function is defined such that $\delta(t)=0$ for $t\neq 0$; and $\int_{-\infty}^{\infty}\delta(t)dt=1$.

(3), the inverse transform can be found using the Heaviside expansion theorem, namely,

$$L^{-1}\left\{\frac{p(s)}{q(s)}\right\} = \sum_{m=1}^{n} \frac{p(k_m)}{q'(k_m)}\epsilon^{k_m t}$$

where $q(s) = \prod_{m=1}^{n}(s-k_m)$ and the k's are all distinct. It is also assumed in this expansion that p is a polynomial of a degree less than the degree of the denominator q. Note that

$$q'(k_m) = \left.\frac{q(s)}{(s-k_m)}\right]_{s=k_m}.$$

According to this expansion, then

$$e_0(t)]_{n,\delta} = \frac{1}{T}\sum_{m=1}^{n}\left[\frac{Ts-b_{m,n}}{\prod_{m=1}^{n}(Ts-b_{m,n})}\right]_{Ts=b_{m,n}} \epsilon^{b_{m,n}(t/T)}. \tag{5}$$

Response to a unit step function input voltage: In order to find the response to a unit step function[3] voltage input, the expression for the transfer function (3) should be multiplied by $1/s$, the operational expression for the input voltage in this case, and then the inverse transform taken. However

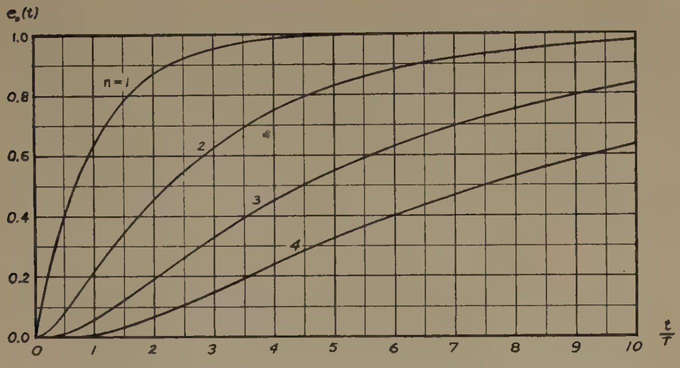

Fig. 2—Output voltage for a unit step function input voltage applied to a low-pass *RC* ladder network of n sections.

$$L^{-1}\left\{\frac{1}{s}F(s)\right\} = \int_0^t F(t)dt$$

so that the response can be found also by integrating (5) between 0 and t. Therefore

$$e_0(t)]_{n,U} = 1 + \sum_{m=1}^{n}\frac{1}{b_{m,n}}\left[\frac{Ts-b_{m,n}}{\prod_{m=1}^{n}(Ts-b_{m,n})}\right]_{Ts=b_{m,n}} \epsilon^{b_{m,n}(t/T)}. \tag{6}$$

Fig. 2 is a graph of the output voltage for one to four sections. Since these are the most important cases in practical applications, (6) is expanded below for n from one to four. $(u=t/T)$

$$e_0(t)]_{1,U} = 1 - e^{-u}$$

$$e_0(t)]_{2,U} = 1 - 1.171e^{-0.382u} + 0.171e^{-2.618u}$$

$$e_0(t)]_{3,U} = 1 - 1.220e^{-0.198u} + 0.280e^{-1.555u} - 0.060e^{-3.247u}$$

$$e_0(t)]_{4,U} = 1 - 1.241e^{-0.121u} + 0.333e^{-1.000u} - 0.120e^{-2.347u} + 0.028e^{-3.532u}.$$

B. High-Pass RX Ladder Structures

The high-pass form of *RC* ladder networks as shown in general form in Fig. 3 can be treated in a manner similar to that given in the preceding discussion of low-pass ladder networks.

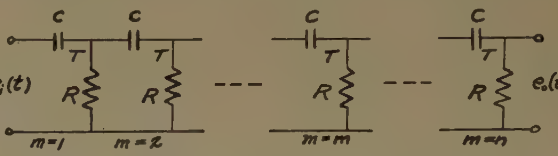

Fig. 3—Generalized high-pass *RC* ladder network.

Both forms of the transfer function can be easily found from the previous results by merely replacing Ts by its reciprocal. Thus

$$\frac{E_o(s)}{E_i(s)} = \frac{(Ts)^n}{\sum_{m=0}^{n} c_{m,n}(Ts)^m} \tag{7}$$

where

$$c_{m,n} = a_{(n-m),n} = \frac{(2n-m)!}{(2n-2m)!m!} = \binom{2n-m}{m} \tag{8}$$

Equation (7) can be factored into the form

$$\left.\frac{E_o(s)}{E_i(s)}\right]_n = \frac{1}{\prod_{m=1}^{n}\left(\frac{1}{Ts}-b_{m,n}\right)}$$

so that

$$\left.\frac{E_o(s)}{E_i(s)}\right]_n = \frac{s^n}{\prod_{m=1}^{n}\left(s-\frac{1}{Tb_{m,n}}\right)}. \tag{9}$$

Response to a unit step function input voltage: Since (9) contains s to the same power in both the numerator and denominator, the unit impulse response cannot be found directly by taking the inverse transform of the transfer function unless division is performed first. This is not the most convenient way to determine the impulse response for the general case, however. For this reason, the response to a unit step function voltage is determined first.

$$e_o(t)]_{n,U} = L^{-1}\left\{\frac{s^{n-1}}{\prod_{m=1}^{n}\left(s-\frac{1}{Tb_{m,n}}\right)}\right\}.$$

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[3] The unit step function $U(t)=0$ for $t<0$ and 1 for $t>0$.

Then

$$e_o(t)\big]_{n,U} = -\sum_{m=1}^{n} \frac{1}{b_{m,n}} \left[\frac{Ts - b_{m,n}}{\prod_{m=1}^{n} (Ts - b_{m,n})} \right]_{Ts=b_{m,n}} \epsilon^{1/b_{m,n}(t/T)}. \quad (10)$$

This last expression is seen to be very similar to (6) for the low-pass network. The coefficients of the terms have the same numerical values, but the coefficients of the exponents are the reciprocals of those before. The first four expressions for the output voltage are

$$e_o(t)\big]_{1,U} = e^{-u}$$

$$e_o(t)\big]_{2,U} = 1.171e^{-2.618u} - 0.171e^{-0.382u}$$

$$e_o(t)\big]_{3,U} = 1.220e^{-5.049u} - 0.280e^{-0.643u} + 0.060e^{-0.308u}$$

$$e_o(t)\big]_{4,U} = 1.241e^{-8.291u} - 0.333e^{-1.000u} + 0.120e^{-0.426u} - 0.028e^{-0.283u}.$$

These four equations are plotted in Fig. 4.

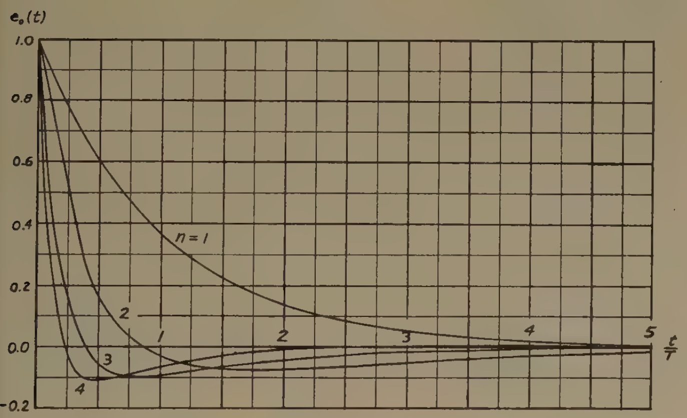

Fig. 4—Output voltage for a unit step function input voltage applied to a high-pass *RC* ladder network of *n* sections.

Response to a unit impulse function input voltage: The output voltage for a unit impulse input voltage can now be determined from the expression for the response when a unit step function voltage is applied. One of the fundamental relations from Laplacian operational calculus is the transform of a derivative of a function $F(t)$, namely,

$$L\{F'(t)\} = sL\{F(t)\} - F(+0).$$

Let $F(t)$ equal $e_0(t)\big]_{n,U}$ for the high-pass case. Then $F(+0)=1$. However, it is important to notice that $sL\{F(t)\}$ is then the transfer function and its inverse Laplace transform is the output voltage for a unit impulse voltage input. Then

$$e_o(t)\big]_{n,\delta} = \delta(t) + F'(t)$$

so that

$$e_o(t)\big]_{n,\delta} = \delta(t) - \frac{1}{T}\sum_{m=1}^{n} \frac{1}{b_{m,n}{}^2} \left[\frac{Ts - b_{m,n}}{\prod_{m=1}^{n} (Ts - b_{m,n})} \right]_{Ts=b_{m,n}} \epsilon^{(1/b_{m,n})(t/T)}. \quad (11)$$

C. Response of Resistance-Reactance Ladder Structures to Any Arbitrary Input Voltage Function

When any arbitrary voltage function is applied at the input terminals the output voltage can be found in one of two ways using the previous results. One is to find the Laplace transform of the input voltage and multiply this expression by the transfer function. The output voltage as a function of time is then the inverse transform of this product.

The output voltage can also be found in any particular case by using a superposition integral. By such a means the input voltage can be considered to be the sum of an infinite number of step function or impulse function voltages with different amplitudes and time displacements. Thus an input voltage can be written as

$$e_i(t) = e_i(0)U(t) + \int_0^t \frac{\partial e_i(\tau)}{\partial \tau} U(t-\tau)d\tau, \quad (12)$$

where $U(t)$ is the unit step function. Likewise, also

$$e_i(t) = \int_0^t e_i(\tau)\delta(t-\tau)d\tau \quad (13)$$

where $\delta(t)$ is the unit impulse function.

In a similar manner the output voltage can be considered as the superposition of the responses to an infinite number of either step or impulse functions. Then if the output voltage is applied at time equal to zero,

$$e_o(t)\big]_{n,e_i} = e_i(0)\left[e_o(t)\right]_{n,U} + \int_0^t \frac{\partial e_i(\tau)}{\partial \tau} \left[e_o(t-\tau)\right]_{n,U} d\tau \quad (14)$$

or

$$e_o(t)\big]_{n,e_i} = \int_0^t e_i(\tau)\left[e_o(t-\tau)\right]_{n,\delta} d\tau, \quad (15)$$

where $e_o(t)\big]_{n,U}$ is the output voltage from an n-section ladder network when a unit step function voltage is applied at the input, and $e_o(t)\big]_{n,\delta}$ is the output voltage from a ladder network of n sections when a unit impulse voltage is applied at the input terminals. By either (14) or (15) the output voltage from a resistance-reactance ladder network of n sections can be found using the appropriate previously derived expressions. Equations (14) and (15) could also be obtained by the convolution of the input voltage and the transfer function.

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Contributors to Proceedings of the I.R.E.

J. I. Bohnert

John I. Bohnert (M'46) was born in Pittsburgh, Pa., on August 15, 1910. He received the B.S. degree in mathematics from Carnegie Institute of Technology in 1932, and the M.A. and Ph.D. degrees in mathematics from the University of Pittsburgh in 1935 and 1940, respectively.

Until 1942, Dr. Bohnert taught mathematics and science. From 1942 through 1945 he worked at the MIT Radiation Laboratory on microwave antennas. Since December, 1945, he has been employed at the Naval Research Laboratory, in Washington, D.C., and at present is the head of the Antenna Research Branch.

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Robert J. Bibbero (M'49–SM'50) was born in San Francisco, Calif., on April 15, 1917. He received the B.S. degree in chemistry from the University of California in 1938 and then performed graduate work in chemical engineering on a University of Michigan fellowship during 1938 and 1939.

He was a research engineer in charge of the test laboratory of Moore Business Forms, Inc., in California until 1942, when he was called on active duty as ordnance officer with the U. S. Navy. He completed training at Bowdoin College (radio engineering) and the Massachusetts Institute of Technology Radar School, and subsequently served as electronics officer in several Naval Shipyards and as Ordnance Officer, Service Squadron 10, Pacific Fleet.

In 1946 he was released from the Navy with the rank of lieutenant commander USNR and joined the research staff of the Linde Air Products Company, where he was engaged in development of chemical pilot plant servo systems, high-temperature ceramics, and automatic control of high temperature furnaces. He resigned in 1948 to attend the University of Buffalo, working toward the Ph.D. degree in physical chemistry and simultaneously completing work for the M.S. degree in electrical engineering, which he received in June, 1948.

In 1948, following a short period of active duty with the Navy at NOTS, Inyokern, and at Mare Island Naval Shipyard, he joined the servomechanisms department of the Bell Aircraft Corporation where he is currently group engineer in charge of component and type tests.

Mr. Bibbero is a senior member of the American Chemical Society, a member of the American Association for the Advancement of Science, and a licensed professional engineer in New York and California. He is delegate to the Technical Societies Council from the Buffalo-Niagara Section of the IRE and chairman of that Civil Defense Committee of that body.

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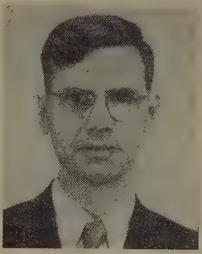

Henry G. Booker

Henry G. Booker (SM'45) was born at Barking, Essex, England, in 1910. He was educated at Cambridge University, where he received the B.A. degree in 1933 and the Ph.D. degree in 1936. He was awarded the Smith's Prize in 1935 and became a Research Fellow of Christ's College in the same year.

From July, 1937, to July, 1938, he was a visiting scientist at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, D. C. During the war he was in charge of theoretical research at the Telecommunications Research Establishment in England, and was decorated by the United States Government. After the war he returned to Cambridge University as a lecturer, and in 1948 became a professor of electrical engineering at Cornell University.

Dr. Booker is an associate member of the Institution of Electrical Engineers, London, by which institution he was awarded Premiums in 1946, 1947, and 1950. He is Chairman of the IRE Wave-Propagation Committee and vice-chairman of certain commissions associated with the International Scientific Radio Union. He is also chairman of a panel of the Research and Development Board. He is a member of Sigma Xi and Eta Kappa Nu.

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For a photograph and biography of V. H. Rumsey, see page 1219 of the October, 1950, issue of the Proceedings of the I.R.E.

W. E. Danforth

W. E. Danforth was born on June 22, 1905, in Buffalo, N. Y. He received the B.S. degree in physics from Union College in 1927. During the following year he worked on insulation problems at the General Electric Company in Schenectady, N. Y. In 1929 and 1931 he received the M.A. and Ph.D. degrees, respectively, from Harvard Graduate School. His thesis work was in the field of dielectrics.

During the year 1931–1932, Dr. Danforth was a research assistant at Harvard University where he was engaged in the study of the growth of single crystals. In the fall of 1932, he went to the Bartol Foundation of the Franklin Institute, in Swarthmore, Pa. There he worked initially in the fields of cosmic radiation and Geiger counters, and later assisted in the development of the Biochemical Research Foundation cyclotron, and designed and supervised construction of the pressurized 2-mev Van de Graaf generator, now in use at Bartol.

In the spring of 1942, Dr. Danforth entered the field of thermionics and cathode research, in which activity he is still engaged. He is, at present, assistant director of the Bartol Research Foundation.

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G. A. Deschamps

George A. Deschamps was born in Vendôme, France, on October 18, 1911. He was graduated from the Ecole Normale Superieure of Paris in 1934, and received the following degrees from the Sorbonne: License in Mathematics and Physics, Diplome d'Etude Superieure, and Agregation in Mathematics. After two years of research in pure Mathematics, one in Paris and one at Princeton University, he joined the Lycée Français de New York as a professor of mathematics and physics. At that time, he also did some work in theoretical physics.

Mr. Deschamps served in the French Army during the war, and joined the Federal Telecommunication Laboratories in 1947, where he is now employed. He is a member of the American Physical Society.

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W. Raymond Evans, Jr. (S'48) was born on July 4, 1925, in Philadelphia, Pa. He attended the William Penn Charter School in Philadelphia, Pa.; Dartmouth College, Massachusetts Institute of Technology, and Tuft College in the Navy College Training Programs during 1944–1946; and the Thayer School of Engineering, Dartmouth College, from 1947 to 1950. He received the B.S. degree in 1948 and the M.Sc. degree in electrical engineering in 1950, both from Dartmouth College.

Mr. Evans was an instructor in mathematics at the William Penn Charter School in the spring of 1947. Since 1948 he has been associated with a program of ionospheric research sponsored by the Office of Naval Research at the Thayer School of Engineering, where he was a research assistant during 1948–1950 and is now a research associate. Mr. Evans is a student member of the American Institute of Electrical Engineers.

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Morris L. Kales

Morris L. Kales was born on August 26, 1910, in New York, N.Y. He received the B.S. and M.S. degrees in mathematics from Massachusetts Institute of Technology in 1933 and 1934, and the Ph.D. in mathematics from Brown University in 1936.

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R. R. Kenyon

R. R. Kenyon (S'49) was born in Middletown, Ohio, on October 6, 1928. He received the B.S. degree in physics from Purdue University in 1950. During the period of his undergraduate work he held positions as a surveyor for the McGraw Construction Co. of Middletown, Ohio, as a research assistant on microwave dielectric heating, and also as a development-design engineer on radio transformers in the Westinghouse graduate student training program.

Mr. Kenyon is at present a graduate research assistant at the Engineering Experiment Station at Purdue University. He is a member of Sigma Pi Sigma and Eta Kappa Nu.

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M. G. Morgan

Millett Granger Morgan (S'42–A'43–SM'48) was born in Hanover, N. H., on January 25, 1915. He attended Cornell University from 1933 to 1938 as a George W. Lefevre Scholar, and was at Stanford University from 1938 to 1940. He received the A.B. degree in physics from Cornell University in 1937; the M.Sc. in engineering from Cornell in 1938; Engineer from Stanford in 1939; and Ph.D. from Stanford in 1946. He was an instructor in electrical engineering at Dartmouth College from 1940 to 1941, and spent the following year teaching at the Massachusetts Institute of Technology. He was associated with the Submarine Signal Company as a research and development engineer, in Boston, Mass., from 1942 to 1944, and at the California Institute of Technology from 1944 to 1946.

Dr. Morgan served as a staff engineer at the United States Navy Electronics Research Group at the University of California during 1946–1947, also lecturing for this period. He was an assistant professor of electrical engineering and assistant dean of the Thayer School of Engineering, Dartmouth College, from 1947 to June, 1950, when he was appointed director of research, his present position. Since October, 1948, he has also been chief investigator on a program of ionospheric research sponsored by the Office of Naval Research. Dr. Morgan is a member of the American Society for Engineering Education, Sigma Xi, and past-president of the Intercollegiate Ski Union. He is currently a member of the IRE Wave Propagation Committee.

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D. L. MacAdam

David Lewis MacAdam was born on July 1, 1910, in Philadelphia, Pa. He was graduated from Lehigh University in 1932 with the B.S. degree in engineering physics. He was then a teaching fellow at the Massachusetts Institute of Technology from 1932 to 1936, when he received the Ph.D. degree for his work on optics, photography, and color measurements. He was a volunteer assistant at the Bartol Research Laboratories during the summer of 1932, specializing in cosmic ray research. In 1936 he became associated with the Eastman Kodak Company, in Rochester, N. Y., where he is now research associate.

Dr. MacAdam is a co-author of the MIT "Handbook of Colorimetry," and also of the "Science of Color," a report of the Optical Society Colorimetry Committee, now in press. He has published numerous papers on the measurement of color, color vision, and applications to color photography in various professional journals and magazines. He is active in the following organizations: Optical Society of America; United States National Committee of International Commission on Illumination (Technical and Secretariat Committee on Colorimetry) and American Standards Association Sectional Committee on Optics. He attended the 1947 Conference on Color Vision, held at Cambridge University in England.

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P. T. Weeks

P. T. Weeks (A'19–M'28–SM'43) was born in Clarksfield, Ohio, on November 19, 1890. He received the B.A. degree from Oberlin College in 1913 and the Ph.D. degree from Cornell University in 1917. During World War I he worked for the Bureau of Standards and the Signal Corps Development Laboratory at Camp Alfred Vail. From 1919 to 1928, he was employed in the physics laboratory and radio-tube-engineering department of the Westinghouse Lamp Company in Bloomfield, N. J.

From 1928 to the present, Dr. Weeks has been engaged in radio tube engineering at the Raytheon Manufacturing Company.

Correspondence

Relation of Nyquist Diagram to Pole-Zero Plots*

Mr. Harman, in his letter, "Relation of Nyquist diagram to pole-zero plots,"[1] has attempted to show that the Nyquist diagram and the pole-zero plot give equivalent stability criteria. His method was to examine one particular circuit, and since for this case it was obvious that the two plots gave the same criteria, he concluded that the two approaches are equivalent.

This can hardly be said to constitute a proof of the equivalence. As a matter of fact, "equivalence" is not quite the proper term. The pole-zero plot criterion follows from our definitions of complex gain and stability. Application of theorems from the theory of functions of complex variables gives us a more convenient graphical method for determining the location and number of poles.

Therefore, in order to investigate the nature of the relation between the pole-zero criterion and the Nyquist criterion we begin by requiring that the complex gain $A/1-A\beta$ does not have a pole in the right-hand half of the complex-frequency plane. For a single-loop feedback system such as that shown by Mr. Harman, this is equivalent to requiring that $1-A\beta=0$ have no roots in the right-hand half of the complex-frequency plane.

We may investigate the roots of $1-A\beta$ by plotting $A\beta$ as a function of $j\omega$ from ω from $-\infty$ to $+\infty$. What we actually plot is the locus of the tips of the vectors $A\beta(j\omega)$. The vectors drawn from the point 1, 0 correspond to the plot of $1-A\beta(j\omega)$, as may be readily seen from Fig. 1.

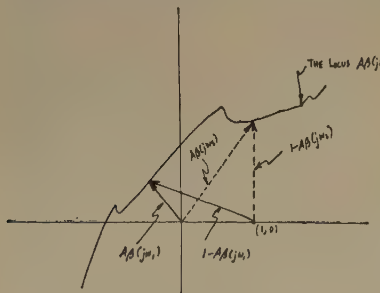

Fig. 1—Nyquist plot of $A\beta(j\omega)$ showing relation between the vectors $A\beta(j\omega)$ and $1-A\beta(j\omega)$.

Rewording some of the results of complex function theory,[2] we may say that the number of complete encirclements of the point 1, 0 of the locus $A\beta$—or the number of rotations the vector $1-A\beta$ makes as ω goes from $-\infty$ to $+\infty$—is equal to the number of zeros of $1-A\beta$ in the right-hand plane. This is a special case of a more general theorem which may be applied to multiloop systems, but here we have only considered single-loop feedback.

Thus we see that the relation between the pole-zero plots and the Nyquist diagram is not mysterious and is completely general. The pole-zero plot shows where the poles are; the Nyquist diagram can be used to tell how many, if any, poles are in the right-hand half of the complex frequency plane.

HERBERT F. SPIRER
Cornell University
Ithaca, N. Y.

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* Received by the Institute, February 5, 1951.

[1] W. W. Harman, "Relation of Nyquist diagram to pole-zero plots in the complex frequency plane," PROC. I.R.E., vol. 38, p. 1454; December, 1950.

[2] H. W. Bode, "Network Analysis and Feedback Amplifier Design," D. Van Nostrand and Co., Inc., New York, N. Y., pp. 137–169; 1945.

Notes on TV Waveform Monitor Frequency Response*

In the IRE "Standards on Television"[1] close limits on frequency response were specified in an attempt to obtain correct level indications and to suppress spurious responses. The following tests were made in order to evaluate the general applicability of this Standard:

1. Response to clean sharp pulses to determine if the measuring instrument introduces spurious responses.
2. Response to video with spikes and noise to determine ability to preserve the significant levels as outlined in the Standard.

In order to obtain a comparative evaluation, a very wide-band scope was compared with the IRE rolloff and with a sharp cutoff of twice the bandwidth (3 db) of the IRE curve. It was felt that the cost of building an amplifier with either of the limited characteristics would be about the same. The steady-state response curves are shown in Fig. 1. The pictures for various conditions of operation are arranged in columns, Fig. 2, the first of which is for the wide-band scope, the second for the IRE rolloff, the third for the sharp cutoff, and the fourth for transmission through both a sharp cutoff and the IRE rolloff. Each row represents one signal input condition.

Row 1 shows monoscope with hash and spikes. Both limited responses reduce the peak-to-peak indication by about 10 per cent. It is still readily apparent that there is trouble in the system.

Row 2 shows a clean sharp horizontal driving pulse. The sharp cutoff response indicates overshoot and ringing, but the IRE response does not.

Row 3 shows a horizontal driving pulse with a spike 0.06 microsecond wide at the trailing edge. The IRE response indicates a pulse with a spike of about 20 per cent amplitude. The sharp cutoff response rings.

Row 4 is the same as Row 3, except with reduced vertical deflection and a greater writing speed.

Row 5 shows a horizontal driving pulse with a spike 0.3 microsecond wide at the trailing edge. The IRE response indicates a pulse with a spike of somewhat reduced amplitude. The sharp cutoff response rings. The fourth column shows the signal after passage through the sharp cutoff and then the IRE response. The ringing produced in the sharp cutoff is passed through and shown as ringing by the IRE response.

Row 6 is the same as row 5, except for a greater writing speed.

Row 7 shows a horizontal driving pulse with both positive and negative spikes of 0.06 microsecond width. The IRE response shows only a slight kink and the sharp cutoff response rings. This signal might be thought of as one cycle at 8.3 mc. The IRE response is about 20 db down at this frequency. The tendency of the sharp cutoff response to ring at the cutoff frequency is very great, as the waveform shows.

Conclusions.—1. The significant levels as specified in the Standard will be indicated with about the same reduction by either limited response.

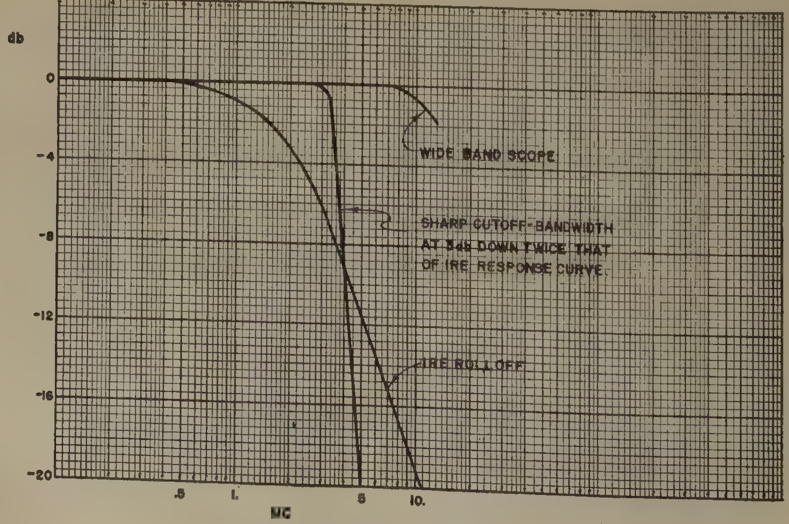

Fig. 1—Steady-state response curves.

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* Received by the Institute, February 9, 1951.

[1] "Standards on Television," PROC. I.R.E., vol. 38, pp. 551–555; May, 1950.

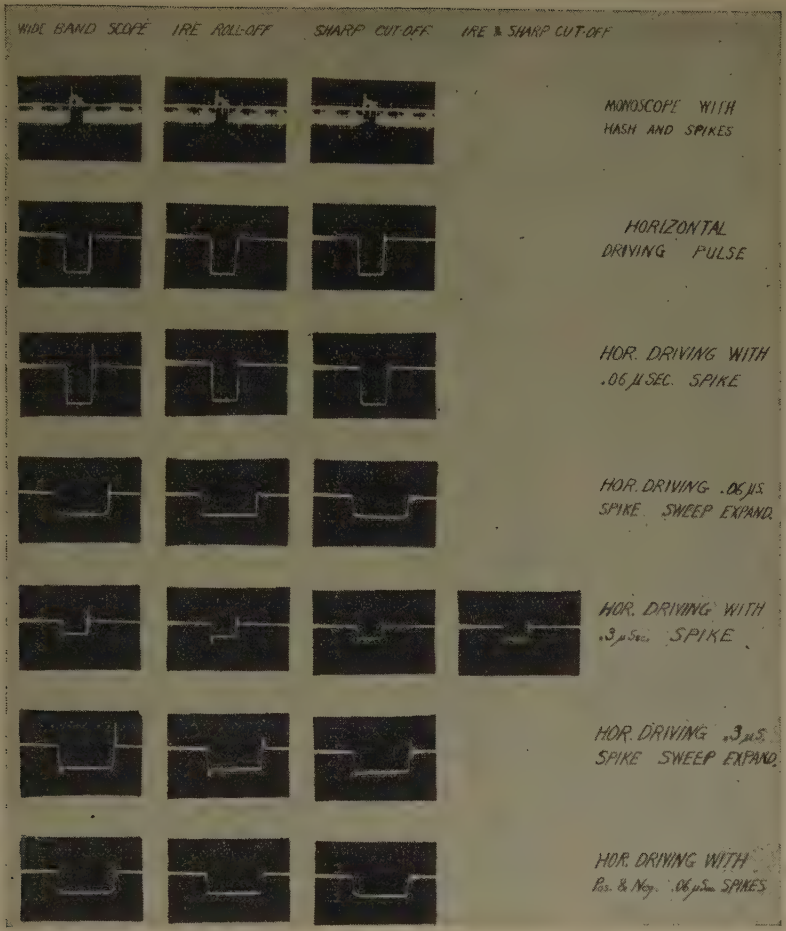

Fig. 2—Transient responses.

2. A clean pulse will be indicated as a clean pulse by the IRE response, but will show overshoot and ringing for the sharp cutoff response.

3. A pulse with spikes will be indicated as a pulse with spikes of reduced amplitude by the IRE response. Sharp spikes will be converted to ringing at the cutoff frequency by the sharp cutoff response.

4. If the pulse is followed by ringing, it will be indicated as a pulse with ringing by the IRE response. The tendency to ring at the cutoff frequency is very strong for sharp cutoff characteristics.

The work outlined shows that the IRE response does not result in spurious indications such as are obtained when the bandwidth is extended at the expense of steepening the rate of cutoff. Hence, for a given over-all gain and number of tubes, the IRE response is an excellent choice.

W. L. Hurford
General Electric Company
Syracuse, N. Y.

"Communication Circuit Fundamentals"*

The above-titled book, reviewed in the May, 1950, issue of the Proceedings of the I.R.E., was prepared as part of a correspondence course and has been very successfully used over the past 15 years to train college and professional radio and communication engineering level students at home. Extensive instructional aids have been developed by the Cleveland Institute of Radio Electronics to accompany this text material, thus personalizing the instruction by forming a link between textbook and student. For isolated ambitious students we believe this method to be the most practical way of obtaining a thorough systematized training.

Furthermore, the text material is presented on an inductive basis, thus making it possible to effectively apply the spiral method of training. For example, Ohm's and Kirchhoff's laws are first applied to direct-current circuits, and then later on these same laws are applied to sinusoidal alternating-current circuits. Many of the subjects in this book are treated for the first time in a rather simple fashion. Then in the books which follow, "Communication Networks" and "Audio and Radio Facilities," many of the same subjects will be treated on a higher level, because by that time the students can readily assimilate the material.

The reviewers' criticisms lose much weight when the above purpose and methods are kept in mind. Then, the reviewer criticizes the use of space vectors to represent impedance vectors because they are different from rotating or time vectors used to represent voltage and current vectors (see page 159). The author contends that it is more appropriate to represent a vector with a vector than by some other means. In this case, there is a need for two distinguishable types of vectors to minimize confusion.

Another criticism is that the partial derivatives used in the discussion of vacuum-tube parameters is incomplete because the other parameters held constant are not specified. However, by the very definition of partial derivatives, it is understood that the other parameters are held constant (see page 293).

Carl E. Smith
United Broadcasting Company, and
Cleveland Institute of Radio Electronics
Cleveland, Ohio

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* Received by the Institute, November 1, 1950.

A Helix Theorem*

The helical beam antenna or axial-mode helix possesses a number of unusual characteristics. It operates as an end-fire beam antenna generating waves that are circularly polarized, or nearly so. This type of radiation is associated with the T_1 transmission mode which tends to be dominant when the helix circumference is of the order of 1 wavelength.[1,2] Perhaps the most remarkable property of the axial-mode helix is that this type of radiation persists over about a 2-to-1 range in frequency with the directivity or gain close to maximum at all frequencies in that range. This results from a natural adjustment of the phase velocity of wave propagation along the helix to approximately the proper value required at each frequency for making the directivity of the antenna a maximum. That is, a given helix automatically produces about the highest directivity possible for an antenna of its size, and does this over a considerable bandwidth. If the phase velocity remained constant (as a function of frequency), the bandwidth of the antenna would be only a few per cent instead of nearly 2 to 1. This is because the pattern is especially sensitive to the phase velocity.

Although no rigorous demonstration is available, it appears from both pattern and direct phase-velocity measurements that if the increased or maximum directivity condition is not obtained exactly, it is, nevertheless, approximated quite closely when the T_1 mode is dominant. In order to state this unique property in a concise manner, the following theorem is postulated:

> *When the circumference of an axial or end-fire helix is about one wavelength (T_1 transmission mode dominant), there is a band of frequencies over which the phase velocity of wave propagation on the helix tends toward a value that makes the directivity a maximum.*

A corollary to this theorem may also be expressed as follows:

> *There is a band of frequencies over which the phase velocity of the T_1 transmission mode tends toward a value that makes the directivity of the helix a maximum.*

These theorems apply in particular to helices of at least a few turns with pitch angles between 10 and 15 degrees.

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Columbus 10, Ohio

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* Received by the Institute January 26, 1951.

[1] J. D. Kraus, "The helical antenna," Proc. I.R.E. vol. 37, pp. 263–272; March, 1949.

[2] J. D. Kraus, "Antennas," McGraw-Hill Book Co., New York, N. Y., pp. 173–212; 1950.

Institute News and Radio Notes

TECHNICAL COMMITTEE NOTES

The **Standards Committee,** under the Chairmanship of J. G. Brainerd, held a meeting on March 22, 1951, during the IRE National Convention at the Waldorf-Astoria Hotel. After reviewing the work accomplished by the Committee during the past two years, Professor Brainerd introduced J. W. McRae, the new Standards Coordinator, and Axel G. Jensen, incoming Standards Committee Chairman, both of whom addressed the gathering, whereupon an open discussion took place.

The **Standards on Electroacoustics: Definitions of Terms, 1951,** was approved by the Institute, and appears in this issue of the PROCEEDINGS. Reprints will be available within a short time from Headquarters for a nominal charge.

At the meeting of the Standards Committee on February 18, J. G. Brainerd presiding, Axel G. Jensen reported on a recent meeting of the **Co-ordinating Committee,** of which he is Chairman, which was held for the purpose of a general discussion on how the Committee might best be of service to CCIR.

The Institute has appointed Chairmen and Vice-Chairmen for the various IRE Technical Committees for the term May 1, 1951, to April 30, 1952. The appointments are as follows: **Annual Review,** Ralph R. Batcher, Chairman, Trevor Clark, Vice-Chairman; **Antennas and Waveguides,** A. Gardiner Fox, Chairman, D. C. Ports, Vice-Chairman; **Circuits Committee,** Chester H. Page, Chairman, W. R. Bennett, Vice-Chairman; **Electroacoustics,** E. S. Seeley, Chairman, B. B. Bauer, Vice-Chairman; **Electron Tubes and Solid-State Devices,** A. L. Samuel, Chairman, G. D. O'Neill, Vice-Chairman; **Electronic Computers,** Nathaniel Rochester, Chairman, Robert Serrell, Vice-Chairman; **Facsimile Committee,** R. J. Wise, Chairman, Henry Burkhard, Vice-Chairman; **Industrial Electronics,** John Dalke, Chairman, Eugene Mittelmann, Vice-Chairman; **Measurements and Instrumentation,** Francis J. Gaffney, Chairman; **Mobile Communication,** F. T. Budelman, Chairman, Alexander Whitney, Vice-Chairman; **Modulation Systems,** W. G. Tuller, Chairman, J. G. Kreer, Jr., Vice-Chairman; **Navigation Aids Committee,** Peter C. Sandretto, Chairman, Charles J. Hirsch, Harry R. Mimno, Vice-Chairmen; **Piezoelectric Crystals,** R. A. Sykes, Chairman, W. P. Mason, Vice-Chairman; **Radio Transmitters Committee,** M. R. Briggs, Chairman, A. E. Kerwien, Vice-Chairman; **Receivers,** Jack Avins, Chairman, John D. Reid, Vice-Chairman; **Sound Recording and Reproducing,** H. E. Roys, Chairman, A. W. Friend, Vice-Chairman; **Standards Committee,** Axel G. Jensen, Chairman, Millard W. Baldwin, Jr., L. G. Cumming, Ernst Weber, Vice-Chairmen; **Symbols,** A. G. Clavier, Chairman, K. E. Anspach, Vice-Chairman; **Video Techniques,** W. J. Poch, Chairman, A. J. Baracket, Vice-Chairman; and **Wave Propagation,** H. G. Booker, Chairman, H. W. Wells, Vice-Chairman.

The **Committee on Electron Tubes and Solid-State Devices** held a meeting on February 23, under the Chairmanship of L. S. Nergaard. A great deal of work has been accomplished by this Committee, whose members are currently working on definitions of klystron and magnetron terms. This Committee, in conjunction with the AIEE Committee on Electronics, is sponsoring another Conference on Electron Devices, which will be held at the University of New Hampshire, on June 21 and 22, 1951. Details of the Conference will be announced as plans are completed.

The **Committee on Sound Recording and Reproducing** held a meeting on February 20, H. E. Roys, Chairman, presiding. This Committee has completed work on the proposed Standard on Noise: Definitions and Measurement Procedures, and is continuing its work on standardization of frequency response and distortion.

A meeting of the **Navigation Aids Committee** was held on February 26, Chairman P. C. Sandretto presiding. Work is progressing in this Committee on definitions.

On February 21, a meeting of the **Industrial Electronics Committee** was held under the Chairmanship of D. E. Watts. The Committee has been active in petitioning for the formation of a Professional Group on Industrial Electronics.

The **Circuits Committee,** under the Chairmanship of W. N. Tuttle, held a meeting on March 2. Detailed reports on the progress of work in the various Subcommittees were given by their Chairmen.

The **Proceedings of the Joint Technical Advisory Committee, Volume VI** (Section I, Official Correspondence Between the Federal Communications Commission and the Joint Technical Advisory Committee with Other Items of Correspondence Pertinent to the Actions of the JTAC, July 1, 1949–June 30, 1950; Section II, Approved Minutes of Meetings of the Joint Technical Advisory Committee, July 1, 1949–June 30, 1950) is now available at IRE Headquarters for $4.50 per copy. The JTAC is preparing a paper on "Spectrum Utilization," which will be published in the October issue of the PROCEEDINGS. This paper will be in six sections, and will deal with the various aspects of spectrum utilization.

RADIO AND ELECTRONICS SOCIETY OF INDIA PLANS WINTER EXHIBIT

The Radio and Electronics Society of India, founded recently by the All India Radio Merchants' Association, is planning to hold an international radio and electronics exhibition in Bombay, India, from February 9 to February 29, 1952. Four days will be devoted exclusively to trade, in order to enable participating firms to transact business with, and to demonstrate equipment to prospective buyers in a convenient atmosphere. Further details of the exhibit will be announced at a future date.

JTAC PUBLICATIONS

Listed below are all publications of the Joint Technical Advisory Committee published to date. These are available at the prices indicated from The Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y.

Volume I "Utilization of Ultra-High Frequencies for Television"	$7.50
Volume II "Allocation Standards for VHF Television and FM Broadcasting"...........	$3.00
Volume III "Official Correspondence between the FCC and the JTAC: and Approved Minutes of Meetings of the JTAC. 1 July 1948 to 30 June 1949"..............	$4.50
Volume IV "Comments on the Proposed Allocation of Television Broadcast Services".	$3.00
Volume V "Adjacent-Channel Interference in Monochrome Television"..............	$4.50
Volume VI "Official Correspondence between the FCC and the JTAC, with other items of correspondence pertinent to the Actions of the JTAC: and Approved Minutes of Meetings of the JTAC. 1 July 1949 to 30 June 1950"	$4.50

OAK RIDGE TO HOLD ENGINEERING SYMPOSIUM

The annual Oak Ridge Summer Symposium, sponsored by the Oak Ridge National Laboratory and the Oak Ridge Institute of Nuclear Studies, will be devoted to the subject of nuclear engineering this summer. These symposia are intended for Oak Ridge personnel, representatives of universities and industrial organizations, and other interested individuals.

The symposium will be held from August 27 to September 6. Its leaders will include Oak Ridge National Laboratory personnel and invited visitors. Such subjects as basic nuclear engineering, general nuclear power "philosophy," application of the engineering sciences to nuclear technology, and particularly nuclear engineering education are expected to comprise the program.

PROFESSIONAL GROUP NOTES

The **Committee on Professional Groups** together with the **Administrative Committees** of the **11 Professional Groups** met on March 21 at the IRE National Convention. Each Chairman reported on the activities of his Group during the past year, and discussed plans for the future. Chairman W. R. G. Baker called attention to the minutes of the meeting of the Committee on Professional Groups on March 5, which outline new procedures for Professional Groups: Each Group may make periodic or nonperiodic assessments of its members; any funds accrued from assessments or from proceeds of a conference will be retained by the Group and matched by Institute funds up to the amount of $1,000. This policy will be in effect for established Groups for the period beginning with January 1, 1951, and ending with June 30, 1952. It is understood that in the case of a new Group not fully organized, the period to June 30, 1952, may need to be extended. In the case of a new Group which has not accrued funds, the Chairman of the Committee on Professional Groups will obtain an advance for the purposes of conducting a conference, or for publication needs, and the Group will return the money to Institute Headquarters. Steps to be followed by Professional Groups to implement the new policy will be incorporated into a revised manual for Professional Groups. In the meantime, details may be found in the minutes of the meetings of the Committee on Professional Groups on March 5 and March 21.

The Administrative Committee of the new **IRE Professional Group on Airborne Electronics** held its first meeting on February 15. The Group and the Dayton Section of the IRE will co-sponsor the Airborne Electronics Conference, scheduled for May 23, 24, and 25, 1951, in Dayton, Ohio. A membership drive will be conducted by the Group at the Conference.

A meeting of the Administrative Committee of the **IRE Professional Group on Antennas and Propagation** was held during the National Convention. This Group sponsored a Conference with the United States National Committee of the URSI on April 16, 17, and 18, 1951, at the National Bureau of Standards in Washington, D. C. Abstracts of the papers presented at the Conference will be submitted for publication in the PROCEEDINGS. The Group has indicated its willingness to participate in the IRE West Coast Convention, to be held in San Francisco, Calif., August 22 to 24, 1951.

The **Professional Group on Audio** held meetings of its Administrative Committee and of its entire membership during the IRE National Convention. Officers and members of the Administrative Committee for the coming year were announced. The Group sponsored a full day's technical session at the Convention.

Meetings of the Administrative Committee and of the general membership of the **IRE Professional Group on Broadcast Transmission Systems** were held during the IRE National Convention. The Group sponsored a half-day technical session and a symposium on "The Empire State Story" at the Convention, and, in addition, held a cocktail party at that time. Word has been received at Headquarters that Arthur Stuarts of Troy, N. Y., a member of the Administrative Committee of the Group, is attempting to organize a Sub-Group in his locality.

A meeting of the Administrative Committee of the **Professional Group on Circuit Theory** was held during the Convention. The Group assisted in setting up six technical sessions, with a member of the Administrative Committee presiding at each of them. One of the sessions, a symposium on "New Extensions of Network Theory," was organized by the Group.

The **IRE Professional Group on Instrumentation** held its annual business meeting with the meeting of the Administrative Committee during the IRE National Convention. This Group sponsored a half-day symposium on "Industrial Instrumentation," and a full-day symposium on "Amplification of DC Signals" at the Convention. A Sub-Group is being organized in the Detroit Section.

The **Professional Group on Nuclear Science** held a meeting of its entire membership during the Convention. It organized a symposium on "Nuclear Reactors," and assisted with a session of instrumentation papers in the field of nuclear science.

The **IRE Professional Group on Radio Telemetry and Remote Control** held a business meeting of its members during the National Convention, and sponsored two symposia. One of these dealt with "Telemetering Systems," and the other with "Simulation as an Aid to Design of Remote Control Systems."

The Administrative Committee of the **IRE Professional Group on Vehicular Communications** held a business meeting during the Convention, to which all Group members were invited. The Group's various committees reported on past activities, and plans for a technical meeting next fall were discussed.

A petition to form a **Professional Group on Industrial Electronics** has been received at Headquarters from Eugene Mittelmann of Chicago, and from Carl E. Smith of Cleveland. It is expected that Headquarters will soon receive a petition, also, for the formation of a **Professional Group** in the field of **information theory.**

FOUR IRE MEMBERS RECEIVE MARCONI MEMORIAL AWARDS

The Veteran Wireless Operators Association, an international organization of veteran professional wirelessmen, awarded the Marconi Memorial Medal of Achievement to the following prominent members of the IRE: George F. Shecklen, executive vice-president of the Radiomarine Corporation of America; J. R. Poppele, vice-president and chief engineer of WOR, and president of the Television Broadcasters Association; Louis G. Pacent, president of the Pacent Engineering Corporation; and Haraden Pratt, vice-president and chief engineer of the Mackay Radio and Telegraph Company. The awards were made at a recent celebration of the Veteran Wireless Operators Association's twenty-sixth anniversary.

ELECTRONICS CONFERENCE PROGRAM ANNOUNCED

The Industrial Electronics Conference, to be held at the Hotel Carter, Cleveland, Ohio, on May 22, has announced the following program: The morning session is to include four papers: "Design Procedures in Industrial Electronic Process," by Eugene Mittelmann, consulting engineer; "FCC Interference Standards," by Edward W. Chapin, FCC Laboratory; "Industrial Electronics in Automatic Controls," by Wilfrid L. Atwood; and "Some Research Applications of Industrial Television," by F. A. Friswold, NACA.

In the afternoon the following people are to present their papers: Paul D. Zottu, Electronic Heating Corp., "Dielectric Heating"; E. R. Haberland, Naval Ordnance Laboratory, "A 40-db Logarithm Range Polar Recorder"; C. A. Tudbury, The Ohio Crankshaft Co., "New Applications of Electronic Generators for Induction Heating"; and R. M. Byrne and J. F. Redmond, Goodyear Aircraft Corp., "A High Performance Servomultiplier and Function Generator for Use in an Electronic Analog Computer."

At a dinner which will follow the afternoon session, Marvin Hobbs of the Munitions Board will speak on "The Role of Electronics in the Military Weapons Program."

Calendar of COMING EVENTS

1951 Annual Meeting of the Engineering Institute of Canada, Mount Royal Hotel, Montreal, Canada, May 9–11
Conference on Industrial Electronics, Cleveland, Ohio, May 22
1951 IRE Technical Conference on Airborne Electronics, Biltmore Hotel, Dayton, Ohio, May 23–25
IRE 7th Regional Conference, Seattle, Wash., June 20–22
Electron Devices Conference, University of New Hampshire, Durham, N. H., June 21–22
1951 Summer General Meeting of AIEE, Royal York Hotel, Toronto, Canada, June 25–29
1951 Annual IAS Summer Meeting, 7660 Beverly Blvd., Los Angeles, Calif., June 27–28
Institute of Navigation National Meeting, Hotel New Yorker, New York, N. Y., June 28–30
1951 IRE West Coast Convention, San Francisco, Calif., August 22–24
1951 National Electronics Conference, Edgewater, Beach Hotel, Chicago, Ill., October 22–24
Radio Fall Meeting, King Edward Hotel, Toronto, Ont., Canada, October 29–31.

Note: Programs for Conference on Industrial Electronics, May 22, and 1951 IRE Technical Conference on Airborne Electronics, May 23–25, appear on page 109A of this issue.

IRE Detroit Section Celebrates 25th Anniversary Year

THE year 1951 marks the silver anniversary of the Detroit Section of The Institute of Radio Engineers. This is also the year that the City of Detroit marks its 250th birthday, and, in keeping with the spirit of these two events, a special anniversary program has been planned for the May meeting of the Detroit Section.

K. R. SCHMEISSER
Detroit Section
Chairman

This Section was conceived as a result of the conversation between a radio inspector and the chief engineer of a broadcast station. The results of this discussion were several organizational meetings and an election of officers held, finally, in May, 1926, T. E. Clark was elected Chairman, E. Glatzel, Vice-Chairman, and Walter R. Hoffman, Secretary. Many IRE members in and around Detroit attended this meeting, which was duly publicized in the May 16, 1926, edition of the *Detroit News*. A technical discussion followed the election, and thus another Section was born.

The members of the Detroit Section of the IRE are justly proud of the role that Detroit has played in the progress of the radio communication industry. For instance, Radio Station WWJ, which started broadcasting in August, 1920, is truly a pioneer in its field. Detroit's municipal Police Department, which began experimenting with radio receiver-equipped cars in 1921, and which later received the commercial call letters KOP, is also unquestionably a pioneer in this field. The Detroit Edison Company also contributed to our field of endeavor by instituting power-line carrier transmissions as far back as 1920. Among the many important contributions was the development of the screen-grid tube at the University of Michigan, while another old-timer in the broadcast field was WCX, which had a coast-to-coast listening audience with its "Red Apple Club" program. Space does not permit further dwelling upon early radio developments in Detroit, but it should be noted that many IRE people who were active in the field 25 years ago are not only still active, but are rendering valuable service to the Detroit Section today.

In 1935, the Detroit Section held a National IRE Convention which was well attended and very successful, and in 1941 a summer session in Detroit was again widely attended.

In order to keep the Detroit membership fully informed in Section matters, and fully to publicize the Section meetings, the present Section Chairman, Kurt R. Schmeisser, founded the Detroit Section publication *Crosstalk* several years ago. This publication is not only widely read throughout the State of Michigan, but many requests for it have been received from IRE members in other Sections who are interested in Detroit IRE people and activities. This publication is entirely supported by local advertisers.

Although the name of the IRE infers a preoccupation with radio communication, many of the Detroit Section members are in other widely diversified fields of the electronic science. A number of our members have been instrumental in the formation of national IRE Professional Groups. To name a few, A. B. Buchanan was one of the founders of the Vehicular Communications Group, H. L. Byerlay aided in the formation of the Instrumentation Group, and H. Selvidge helped to form the Nuclear Science Group.

At a recent Executive Committee meeting of the Detroit Section, Chairman Schmeisser proposed that a special Anniversary program should be planned to celebrate 25 years of IRE activities in Detroit; it was decided that this program be scheduled for Saturday, May 26, 1951, to be held at the Engineering Society of Detroit. President Coggeshall and many other well-known IRE people have indicated that the Section will be honored by their presence.

It is perhaps symbolic that the Detroit Section of The Institute of Radio Engineers should celebrate its silver anniversary within the same year that the City of Detroit will celebrate its own 250th birthday. The Detroit Section officers and members are proud of Detroit's contributions and its well-earned title, the "Dynamic Motor City"; they look forward to continued expansion of Section activities in the future, just as the City of Detroit is looking forward to greater achievements.

Industrial Engineering Notes[1]

CONTROLS

The National Production Authority announced recently, in an **amendment to its Construction Order,** that buildings or structures for radio and television broadcasting, plants for the primary purpose of publishing newspapers, and printing establishments operated by publishing companies primarily for publication of books and periodicals may be constructed without authorization from NPA. The new action, NPA explained, is designed to assure the greatest possible freedom of operation to the nation's facilities for the communication of news and educational material. . . . **Loudspeakers now are the limiting factor in civilian radio-television production,** a group of speaker manufacturers emphasized in a conference with NPA Administrator Manly Fleischmann. The shortage of cobalt remains the crux of the speakers industry's problems, the NPA was told. . . . A special task group of the Joint Electron Tube Engineering Council met recently with officials of the National Production Authority to discuss **methods of maintaining tube production lines** in the face of an acute shortage of certain materials. The group, under the chairmanship of A. C. Gable, said that a drastic cut in production of electron tubes loomed because of a shortage of nickel of the type used in pins, cathode sleeves, anodes, and other parts of all types of tubes. . . . Members of the **X-Ray Equipment and Accessories Industry Advisory Committee** told NPA officials that frequent production bottlenecks are being experienced due to the lack of essential components. The Committee said production will be seriously delayed if resistors, relays, circuit breakers, and other components continue to be unavailable. NPA advised the industry representatives that it would assist individual manufacturers engaged in essential production to obtain supplies, and pointed out that a controlled materials plan now being developed will provide for distribution of materials to essential industries. . . . The NPA has issued its previously announced **order cutting the use of iron and steel in radio and television sets,** and all durable and household goods by 20 per cent. The reduction, effective during the second quarter, is based on average quarterly consumption in the first half of 1950. This is the first NPA direct curb put on steel. It specifically covers home, portable and broadcast-band automobile radio receivers, television sets, phonographs, record players, and combinations. NPA, however, decided against curbing the use of aluminum and copper by end-product use, and continued to restrict use of these metals at the fabricator's level. NPA's earlier intentions were modified because it would be "administratively impossible to enforce the restrictions on the use of copper and aluminum in the final consumer durable goods," a spokesman said. He also pointed out that it was felt that the steel cut would accomplish the same purpose.

FIRST FULL-TIME RTMA PRESIDENT ELECTED

Glen McDaniel, 39-year-old lawyer and vice-president of the Radio Corporation of America, was elected first full-time paid president of the Radio-Television Manufacturers Association by the RTMA Board of Directors recently, at the conclusion of a three-day industry conference at the Stevens Hotel, Chicago, Ill. He began his term of office on April 1.

The resignation of Robert C. Sprague as president was effective at that time; however, Mr. Sprague will continue to serve as chairman of the board.

Mr. McDaniel has been associated with the radio-television industry since early in 1946, when he joined RCA Communications, Inc., as vice-president and general attorney. Recently he has been serving on the staff of David Sarnoff, RCA chairman of the board, and Frank M. Folsom, RCA president.

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[1] The data on which these NOTES are based were selected by permission from *Industry Reports*, issues of February 16, February 23, March 2, and March 9, published by the Radio-Television Manufacturers Association, whose helpfulness is gladly acknowledged.

FCC Takes Court Action on Electric Heater Interference

In the first proceeding of its kind instituted by the Federal Communications Commission through the U. S Attorney General, the Federal District Court for the Southern District of New York recently issued an order against the Yonkers Cabinet Co. The concern was directed to show cause why it should not cease its use of a dielectric heater causing interference to radio reception by the United States Coast Guard on the latter's aeronautical frequency (7,530 kc).

New Radio Micropotentiometer

Extremely simple devices which produce radio-frequency voltages at a very low impedance and at a wide range of frequencies have been developed by the National Bureau of Standards. Known as "rf micropotentiometers," they provide accurate voltages from 1 to 10^6 microvolts without the use of attenuators at frequencies up to 300 mc and above. Thus, convenient standards of low voltages are made available, which should greatly reduce equipment and shielding problems encountered in calibration of present-day commercial voltage generators, attenuators, voltmeters, and other radio-frequency equipment. The micropotentiometers should prove especially useful in measurements of radio-receiver sensitivity, the Bureau said.

Complete details on the new device were published in the March issue of *The Technical News Bulletin*, an NBS publication.

OTS Publishes New Report on Electronic Equipment

The Office of Technical Services, U. S. Department of Commerce, has just published a report entitled "Electronic Equipment Construction—New Objectives, New Techniques and New Components."

The report was prepared by the Stanford Research Institute under contract to the Office of Naval Research. It consists of three parts: a description and evaluation of new components, a discussion of new construction techniques, and a survey of research at 62 of the nation's leading electronics development firms and laboratories.

Components covered in detail include fixed and variable resistors, fixed and variable capacitors, high-frequency inductors and transformers, multiple-component units, vacuum tubes, crystals and transistors, frequency-control and transducer devices, power and audio transformers, relays, indicating instruments, connectors, tube sockets, batteries, motors and servomechanisms, insulating materials, switches, and hermetic seals.

New construction techniques receiving special attention include printed circuits and conductor patterns, mechanized construction, unitized construction, hermetic sealing methods, cast resin embedment, and heat removal techniques.

Copies of the 300-page booklet (PB 101 745) may be obtained from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., at a price of $7 per copy.

Supreme Court Upholds TV Film Censor Ruling

The Supreme Court recently upheld a lower court finding that states may not censor motion-picture films shown on television. The high tribunal refused to review a decision to that effect by the United States District Court in Philadelphia, which was later upheld by the circuit court there.

The case resulted from a ruling of the Pennsylvania State Board of Censors that films were not to be projected on television unless previously approved.

Mobilization

Two RTMA spokesmen, W. R. G. Baker, director, RTMA engineering department, and David B. Smith, vice-director, testified recently before the Senate Interstate and Foreign Commerce Committee in opposition to the **military electromagnetic radiation controls bill** (S. 537), through which the President would be empowered to control the operation of all sources of electromagnetic radiation in times of emergency. Dr. Baker explained in detail to the Committee how radiations are affected by electric and electronic equipment of all types, and how it would be necessary literally to stop all the economy of a city to eliminate electromagnetic radiation. Such emergency action, Dr. Baker pointed out, would create confusion and impede civil defense within the areas where all communications are suddenly blacked out. Dr. Baker recommended to the Committee that no action be taken on the proposed bill, and stated his opinion that the present Communications Act of 1934 gives the Government adequate power to meet all emergency situations. Mr. Smith pointed out the extreme extent of the bill as now written, and proposed restrictions to it. RTMA special counsel Edward Wheeler presented the RTMA witnesses. . . . The following outline of the activities of the Research and Development Board, regarding the **reliability of electronic equipment**, was prepared by RTMA director Fred R. Lack at the suggestion of representatives of the parts division: "The Ad Hoc Group on Reliability of Electronic Equipment has been established by the Committee on Electronics of the Research and Development Board, with a directive to survey plans and research and development programs in the area of electronic equipment and its related components with the objective of substantial improvement in the reliability and reduction in the maintenance of such equipment in the military service. The Chairman of the Committee is J. A. Chambers, RDB Committee on Electronics, Rm. 3D124, Pentagon, Washington, D. C. (formerly, Commander in the Bureau of Ships). Senior electronics officers of the Army, Navy, and Air Force represent their respective departments on the Ad Hoc Group, and the RDB Panels on Elecron Tubes and Components are also represented. The Group has embarked on an energetic program to study component deficiencies and the causes of service failures, and to initiate action through established channels for corrective measures, including further development work, if this is required. In the vacuum-tube field where the problem is perhaps most acute, the Ad Hoc Group is looking to the Panel on Electron Tubes, under the chairmanship of A. L. Samuel of the I.B.M. Co., Poughkeepsie, N. Y., to monitor and guide the corrective measures. Similarly, on other components, the Ad Hoc Group is looking to the Panel on Components, whose Chairman is J. H. Koenig of Rutgers University, to organize and supervise the program determined upon. Contracting with industry for activities along this line will be carried on through presently established Army, Navy, or Air Force channels; however, the joint departmental sponsorship and co-ordination provided by the RDB Panel arrangements described above will be noted. The activity of the Ad Hoc Group on reliability of electronic equipment is co-ordinated with, but is in no sense a substitute for the standardizing activities of the Armed Services Electro Standards Agency, with operating headquarters at Fort Monmouth, Eatontown, N. J. . . . **Major General Spencer B. Akin, Chief Signal Officer of the U. S. Army, retired recently,** it has been learned. He served in the top signal position for approximately four years, and was considered by many among the best officers ever to have held the post. General Akin had a notable career during World War II, in which he served as Chief Signal Officer to General MacArthur in the Pacific, and won three decorations for gallantry in action. His future plans have not been announced. Among those understood to be high on the list of possible successors to General Akin are: Major General W. O. Reeder, a former Deputy Chief Signal Officer, and presently Deputy Assistant Chief of Staff for Logistics on the General Staff; Major General Francis Henry Lanahan, who was in command at Fort Monmouth, N. J., and who served as Chief signal Officer of SHAEF during the war; and Major General Jerry V. Matejka, who is currently serving on the Munitions Board, and under whose direction the Electronics Division of that agency operates. . . . The **appointment of Don G. Mitchell,** president of Sylvania Electric Products Inc., **as a special consultant to Under Secretary of the Air Force, John A. McCone,** was announced recently. Mr. Mitchell will assist the Under Secretary and the Air Staff in the procurement of electronic equipment and components under the expanded Air Force procurement program, and in developing means for increasing the number of suppliers of electronic equipment. . . . Chairman John D. Small of the Munitions Board announced the **appointment of Cornelius W. Middleton as vice-chairman for Production and Requirements Management.** Mr. Middleton, an engineer, was connected with Babcock and Wilcox Co., New York, N. Y. He will be responsible for all production and requirements activities of the Munitions Board, including those of the electronics division. Harry K. Clark, who was previously appointed vice-chairman of Production Management, has been named executive vice-chairman of the Munitions Board. William Van Atten, who has been vice-chairman for Staff Management, has become vice-chairman for International Programs.

. K. Zworykin, vice-president of RCA Laboratories gives speech of acceptance after receiving the IRE Medal of Honor during the Annual Banquet.

Distinguished visitors from abroad (left to right): Sir Robert Watson-Watt and Sir Ernest Fisk, former IRE Vice-Presidents; and Murray H. Stevenson, Editor of the *Proceedings of the Institution of Radio Engineers, Australia.*

Robert C. Sprague, chairman of the board and outgoing president of the Radio-Television Manufacturers Association, delivers the principle address during the Annual Banquet.

23,000 Attend IRE National

THE 1951 IRE NATIONAL CONVENTION became the largest meeting ever held in a single field of engineering or science when over 23,000 radio engineers and scientists from the United States and 30 foreign countries gathered on March 19–22 at the Waldorf-Astoria Hotel and Grand Central Palace, overflowing to the Belmont Plaza, in New York City to witness a comprehensive program of 210 technical papers and 280 exhibits. The record-breaking attendance, 5,000 more than in 1950, reflected the increased size and scope of the technical program, the Radio Engineering Show, and the timeliness of the Convention theme, "Advance with Radio-Electronics in the National Emergency."

The papers and exhibits covered every phase of the radio-electronic field, with particular attention being given to the impact of the mobilization effort on industry and to recent developments in television.

Many of the 43 technical sessions were devoted to topics having important application to military and civilian defense needs, such as radar, guided missile control, nuclear instrumentation, air traffic control, gun-aiming computers, and new materials for vacuum tubes and other uses.

Every aspect of television received comprehensive treatment; black-and-white and color, vhf and uhf, transmitters and receivers. Two sessions were devoted to colorimetry and color transmission. Important advances in uhf transmitter tubes were revealed. The new multiple TV antenna atop the Empire State Building was described in full detail. Television picture tubes received their share of attention. One paper, in describing a 30-inch tube, revealed a new 90° deflection-angle technique. Among other television topics discussed were a portable transmitter and camera, subminiaturized amplifiers, mass production techniques, receiver interference from harmonics, uhf converters, and television recording.

View of Exhibits, First Floor, Grand Central Palace.

The subject of circuits was extensively covered in a series of six sessions. One session revealed interesting applications of circuit theory to the study of such phenomena as the spread of rumors and contagious disease. Two Audio sessions were held, with one devoted to loudspeakers. Engineering education was also covered in a special symposium.

It should be noted that of the 43 sessions, 11 were organized by seven IRE Professional Groups, and that the Groups assisted the Technical Program Committee in arranging several additional sessions. A full listing of all sessions and a summarization of each paper may be found in the March issue of the Proceedings.

Speakers' Table at the Annual Banquet

Back row—Head table at Annual Banquet (left to right): W. W. Harman, recipient of the Editor's Award; A. B. Macnee, recipient of the Browder J. Thompson Memorial Prize; J. R. Poppele, president, Television Broadcasters Association; Haradan Pratt, Secretary, IRE; S. L. Bailey, Senior Past President, IRE; R. F. Guy, Junior Past President, IRE; R. C. Sprague, chairman of the board, Radio-Television Manufacturers Association; and A. W. Graf, toastmaster. *Front row*—25th Anniversary head table of first banquet in 1926 (left to right): Melville Eastham, honorary president, General Radio Company; Lloyd Espenscheid, research consultant, Bell Telephone Laboratories; J. V. L. Hogan, president, Hogan Laboratories; and Ralph Bown, director of research, Bell Telephone Laboratories.

Ernst Weber gives the speech of acceptance on behalf of the recipients of the Fellow Award during the Annual Banquet.

At the President's Luncheon (left to right): Raymond F. Guy, 1950 IRE President, giving the gavel of office to his 1951 successor, I. S. Coggeshall; and Alfred N. Goldsmith, Editor, IRE.

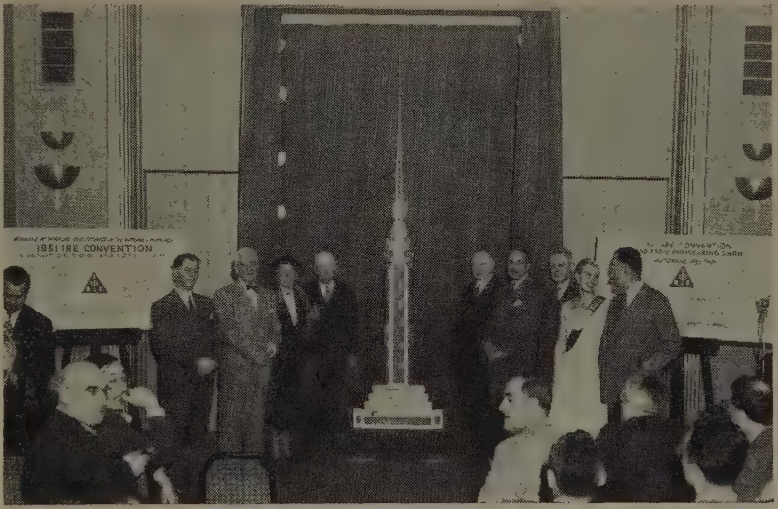
Jack Carter, NBC television comedian, enterta guests at the President's Luncheon as toastmas Raymond F. Guy (at left) looks on.

Convention and Radio Engineering Show

The technical sessions were preceded by a well-attended Annual Meeting at which James W. McRae, director of transmission development for Bell Telephone Laboratories, gave an informative talk entitled "A Challenge and a Promise."

The Radio Engineering Show considerably transcended any previously held. Three floors of Grand Central Palace were filled to capacity as 298 firms displayed over $7,000,000 worth of the latest radio-engineer apparatus. The exhibits featured everything from materials, components, transmitters, receivers, and measuring instruments of all descriptions, to complete communication systems. Coil-winding machines, an electronic organ, a videophone, and color television demonstrations by CBS and by DuMont were among the many interesting demonstrations on view. Much of the equipment on display was characterized by smaller parts, higher powers and frequencies, and the conservation of critical materials.

The Navy, Air Force, and Signal Corps combined to stage a mammoth Armed Services exhibit depicting the latest military electronic apparatus not on the restricted list. Radiation detection devices, cloud-height indicators, telemetering systems, and facsimile equipment were given prominent attention. A number of compact, lightweight versions of World War II communications equipment, such as walkie-talkies and portable teletypewriters, were on view featuring the use of printed circuits, subminiature components, and plug-in units.



Broadcast Dignitaries View Empire State TV Tower

Unveiling of a 14-foot scale model of the new Empire State multiple TV antenna during the Press Cocktail Party. Grouped around the model, from left to right, are: George Sterling, FCC Commissioner; Cmdr. M. W. Loewi, director, DuMont Television Network; Frieda Hennock, FCC Commissioner; Lt. Gen. Hugh Drum, president, Empire State Building, Inc.; Brig. Gen. David Sarnoff, chairman of the board, RCA; P. B. Stephens, business manager, N. Y. *Daily News;* E. M. Webster, FCC Commissioner; Kay Burke, "Miss Empire State"; and E. J. Noble, chairman of the board, American Broadcasting Company.

The IRE Professional Group on Broadcast Transmission Systems arranged for the construction of the model in connection with "broadcast day" during the Convention.

The Starlight Roof of the Waldorf was the scene of two successful social functions. On the first night of the Convention 1,500 people gathered for the "get-together" cocktail party. Television comedian Jack Carter provided excellent entertainment at the President's Luncheon the following day.

The Annual Banquet heard RTMA board chairman R. C. Sprague give the principal address (to appear in a future issue), and saw President I. S. Coggeshall present IRE awards for 1951 (see following pages).

The Women's Activities Committee had its most successful program to date as a record of 283 women registered for the outstanding schedule of tours, matinees, television shows, and fashion shows. The program was highlighted by a women's forum featuring Mrs. Douglas Horton, organizer of the WAVES and now director of NBC; Miss Nadine Miller, director of press and public relations for the Hooperating service; and Miss Beatrice Hicks, president of the Society of Women Engineers.

Speakers' Table at the Annual Banquet (Continued)

Back row—I. S. Coggeshall, President, IRE; V. K. Zworykin, recipient of the Medal of Honor; Alfred N. Goldsmith, Editor, IRE; W. R. G. Baker, Treasurer, IRE; R. B. Dome, recipient of the Morris Liebmann Memorial Prize; and M. J. E. Golay, recipient of the Harry Diamond Memorial Award. Seated at head table out of camera range: Austin Bailey, Convention Vice-Chairman; J. F. Jordan, Chairman, Sections Committee; Ernst Weber, spokesman for recipients of the Fellow Award; and G. W. Bailey, Convention Chairman. *Front row*—Donald McNicol, consulting communication engineer; J. H. Dellinger, radio consultant; E. F. W. Alexanderson, consulting engineer, General Electric Company; Alan Hazeltine, consulting engineer; and L. E. Whittemore, special representative, A T & T.

To Whom Our Laurels Go*

I. S. COGGESHALL

What titular head of this great society, honored by selection to attend to its temporal affairs for a season, has not thrilled, as I do now, to the sheer vastness of the technological outpuring of its collective mind and spirit!

Here at this convention, ushering in the second half of the Radio Century, the technological fecundity of this still young Institute of Radio Engineers continues without abatement. In the Institute's 40th year of service its members are establishing new outposts of science and engineering, as those of the preceding generation erected the citadels of the past. The temptation is strong, but must be resisted, to call the roll of the Institute's past great, just to hear the reverberation of their names, modulated with their achievements, reflecting line-impedance mismatches as they echo down the corridors of Time, to emerge at last into that spatial infinity to which they themselves bequeathed a new order of magnitude.

When the IRE was founded, back in 1912, the frequency band denoting the electrical industry took on the superficial aspects of the spectrum of potassium, displaying two bright lines at zero and 60 cycles per second, and above them a faint continuum standing for the crude transmission of speech over wires. To only a few was vouchsafed at that time a prophetic glimpse of the amazing flash of rainbow extending from C below the bass clef to some 30-thousand-million cycles per second, whose colors represent dispersion from the incandescent crucible which is the radio industry today. To this Institute and its members, (many of them here present, some of them gone to their reward), more than to any other one intellectual group on earth, this vast domain belongs by right of discovery, conquest, settlement, and zealous exploitation.

Yet this society stakes no claim to exclusivity in present occupancy of so great a dominion. Science is a cosmos; engineering knows no confines of organization or geopolitics. Universal recognition of effective work done in this, our estate, is fully due and properly accorded our sister societies in the United States and abroad, the universities, laboratories supported by industry and by the public, privately managed publication media, and all other sources of the new and original idea wherever found. This Institute can be generous with its recognition of work done in neighboring vineyards without diluting its pride in the achievements of those who have labored with us through the heat of the day.

Nevertheless, within the domain of electrons and electromagnetic waves, no honors are more dearly held than those bestowed by The Institute of Radio Engineers. For a long history of continuous accomplishment by its members, wherein today's horizon marks tomorrow's nearer landmark, has created an uncrowned peerage sitting in judgment over more recent achievements and the processes by which they have been derived. Recognition by so high authority is pure gold which the Institute mints—its imprimatur more prized by recipients than coinage measured in grains of fineness.

And acceptance of honor so proferred, in reflex honors the Institute, by adding to the intrinsic worth of the accolade when subsequently conferred upon others. Hence, our Medal of Honor and the Morris Liebmann Memorial tonight scintillate with the reflected glory of those on whom they have been bestowed in the past, and our less venerable decorations irradiate additional splendor as the years go by. We do well, then, to guard these insignia like jewels, to make of their award an occasion of state, and to venerate the recipients for their achievements, of which these laurels are but tokens.

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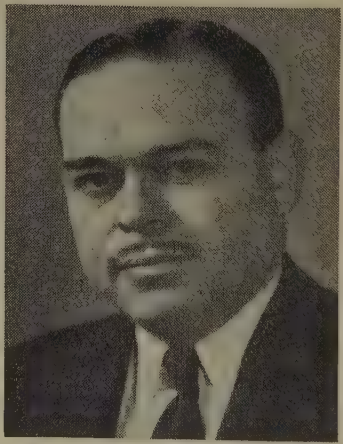
* Substantive content of the address by the President of the IRE in presenting the Medal of Honor and other awards at the Annual IRE Banquet on March 21, 1951.

IRE Awards, 1951

Medal of Honor

V. K. Zworykin

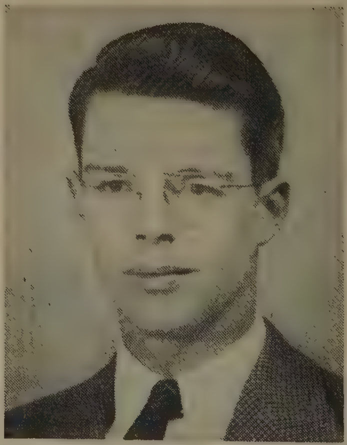
"For his outstanding contributions to the concept and development of electronic apparatus basic to modern television, and his scientific achievements that led to fundamental advances in the application of electronics to communications, to industry, and to national security."



Morris Liebmann Memorial Prize

R. B. Dome

"For many technical contributions to the profession, but notably his contributions to the inter-carrier sound system of television reception, wide-band phase-shift networks, and various simplifying innovations in FM receiver circuits."



Browder J. Thompson Memorial Award

A. B. Macnee

"For his paper entitled 'An Electronic Differential Analyzer,' which appeared on pages 1315–1324 of the November, 1949, issue of the Proceedings of the I.R.E."

Harry Diamond Memorial Award

Marcel J. E. Golay

"For his many contributions in the over-all Signal Corps research and development program, and particularly for his accomplishments leading toward a reduction in the infrared-radio gap."

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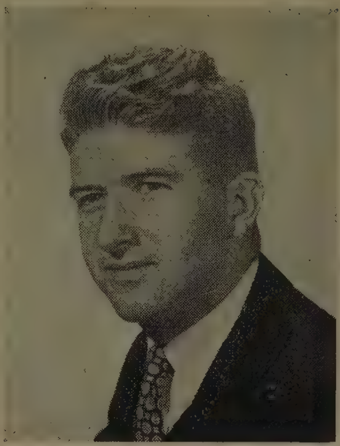

Editor's Award

W. W. Harman

"For his paper entitled, 'Special Relativity and the Electron,' which appeared on pages 1308–1314 of the November, 1949, issue of the Proceedings of the I.R.E."

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Fellow Awards

Robert Adler

"For his developments of transmission and detection devices for frequency-modulated signals and of electromechanical filter systems."

J. G. Brainerd

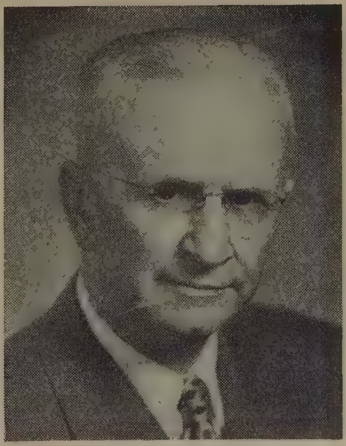
"For contributions to the technical literature, to the teaching profession, and to the art of electronic computation."

C. G. Brennecke

"Teacher, engineer and physicist, in recognition of his excellent work in basic research."

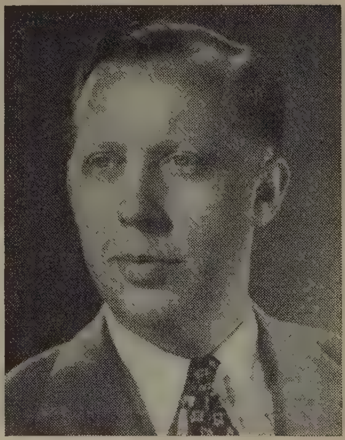
R. D. Campbell

"For his work in the internationally important field of radio-frequency allocations."



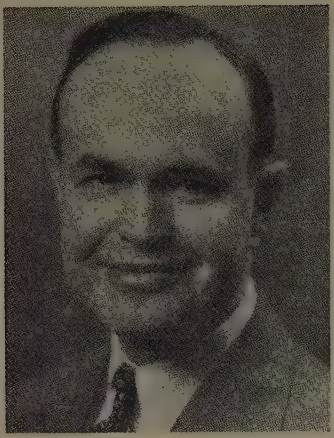
R. W. Deardorff

"For his technical contributions to communications and his work on behalf of the radio-engineering profession."



John H. DeWitt, Jr

"For his achievements in the field of radio-broadcast engineering, and for his demonstration of radar reflections from the moon."



Harold F. Elliott

"For his contributions of important mechanical advances in both the civil and the military electronic arts."

Clifford G. Fick

"For his leadership and contributions in the development and design of a wide variety of radio and radar equipment."

E. L. Ginzton

"For numerous contributions to the microwave art, especially in the development of high-power klystrons."

William M. Goodall

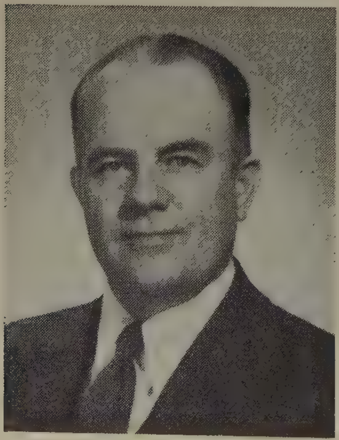
"For his researches in the fields of ionospheric phenomena and pulse communications."

John T. Henderson

"For his contributions in the field of radio direction-finding systems, and in particular, for his work in the development of Canadian radar during the war."

C. J. Hirsch

"For his contributions in the fields of radio-broadcast receivers, electronic aids to navigation, and electronic computers."



William E. Jackson

"For his technical contributions to electronic aids to air navigation and control, and for his administrative contribution in the Civil Aeronautics Administration."

J. B. Johnson

"For his discovery of the limiting noise in electric circuits and his early developments in cathode-ray tubes."

A. G. Kandoian

"For his important contributions in the application of graphical methods to the analysis of detector and output tube performance."

C. E. KILGOUR

"For his contributions in the application of graphical methods to the analysis of detector- and output-tube performance."

T. J. KILLIAN

"For his enlightened guidance of basic scientific research."

J. B. KNOX

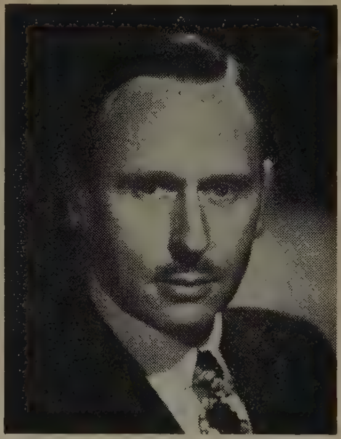
"For contributions to the development and design of radio transmitters and communication systems, and radio aids to air navigation in Canada."

V. D. LANDON

"For contributions to communication system, filter, and noise theory."

GEORGE LEWIS

"In recognition of important pioneering contributions, including the objective coordination of many management and engineering activities."

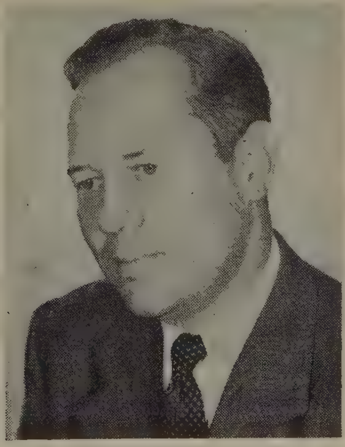


HARRY R. LUBCKE

"For courageous pioneering work in television production and transmission."

DAVID G. C. LUCK

"For his early development of the omnidirectional radio range."

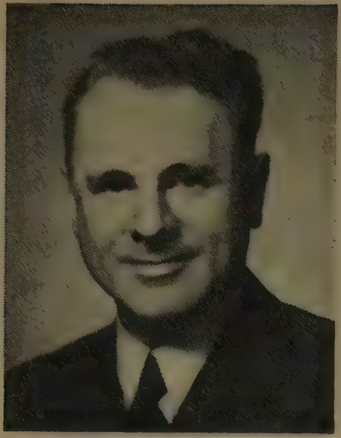


JOHN F. MORRISON

"In recognition of his contributions in the field of broadcast-antenna and transmission design."

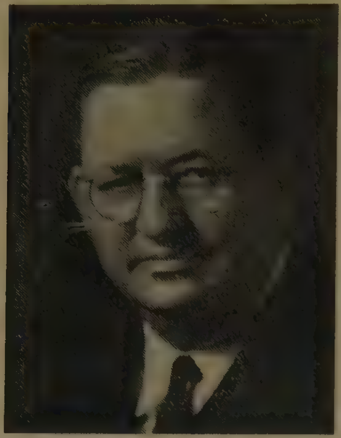
G. A. MORTON

"For his contributions to research on electronic imaging and electronic applications in the field of nucleonics."



G. W. OLIVE

"For major contributions to the development of radio broadcasting in Canada, and in particular, for the engineering and organization of Canadian Overseas broadcasting service during the war."



*O. W. PIKE

"For his pioneering contributions and his leadership in the development and design of industrial and radio tubes."

* Deceased

L. E. REUKEMA

"For research in electromagnetic radiation and a distinguished record in the teaching of electronics."

H. W. G. SALINGER

"For his original contributions to electronoptic and filter theory."

OTTO H. SCHADE

"For many contributions in the development of circuits and electronic devices used in television."

DOMINIC F. SCHMIT

"For outstanding leadership and direction in many phases of radio engineering."

W. E. SHOUPP

"For his work in applying electronics to nuclear research."

P. F. SILING

"For contributions to the establishment and administration of national and international radio-frequency allocations."

H. R. SKIFTER

"For his technical contributions to radio broadcasting and leadership of electronics research and development."

B. R. TEARE, JR.

"For contributions in teaching and research in the fields of engineering methods, network theory, and servomechanisms."

GORDON N. THAYER

"For his leadership in the engineering of long-distance microwave links for network television and multiplex telephony."

HENRY P. THOMAS

"In recognition of his pioneering contributions in the development of high-frequency and microwave equipment and communication systems."

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WILLIAM C. TINUS

"For his contributions to fire control radar, and his guidance of postwar electronic developments for military purposes."

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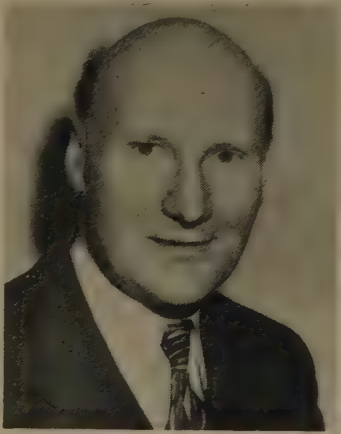


◆

ERNST WEBER

"For outstanding service and achievement in the field of engineering education and for his many contributions to electromagnetic theory."

◆

R. H. WILLIAMSON

"For his accomplishments in the design of very-high-power radio transmitters and for his contributions to transmitter industrial standards.

W. T. WINTRINGHAM

"For his studies of colorimetry and color television, and for his work on television interference problems."

G. A. WOONTON

"For distinguished service as a teacher of electronics and for varied contributions through research in the same field."

IRE People

Chester W. Rice (A'16–M'26–F'28), a retired General Electric Company engineer, died recently at the Deaconess hospital in Boston, Mass.

The son of the late E. W. Rice, former GE president, he was born in Lynn, Mass., in 1890. In 1911, shortly after his graduation from Harvard, he entered the employ of General Electric, with whom he was to maintain his association until his retirement in January, 1950.

A pioneer in microwave radio transmission, he was one of the first to detect a reflection of these waves from airplanes, and so to discover a forerunner of radar. He also pioneered in the building of equipment which would automatically track flying planes, once the plane was in the path of the directional radiation.

The Rice-Kellog radio loudspeaker, for the development of which he was in part responsible, is still used, in principle, in all present-day speakers.

Mr. Rice contributed to the work on the sonic altimeter, a device which measures height by sound. At the end of World War I, his work involved the detection of submarines through the use of sound; this method was used by the Navy until the discovery of radar made it obsolete.

He was also instrumental in founding the hydrogen-cooled generator, while working on the application of hydrogen as a heat removal agency in large generators. This work led to expansion and improvement in efficiency in the electric power generating field. His work in this field, which he continued even after retiring from GE, is used in the design of every large power generator, as it included sealing the hydrogen in its proper place to prevent any leakage.

Mr. Rice was a member of the American Institute of Electrical Engineers, the American Chemical Society, and the American Society of Mechanical Engineers.

George M. Lebedeff (A'36–VA'39) was recently appointed chief engineer of the Lenkurt Electric Company in San Carlos, Calif.

A graduate of the University of California, Mr. Lebedeff began his career as a junior engineer for the Federal Telegraph Company in Palo Alto, Calif. Before joining the Lenkurt Company, he was affiliated with Stanford Products, Ltd., in San Francisco, and Heintz & Kaufman, Ltd., in South San Francisco, Calif.

Martin A. Edwards (SM'48) has been appointed engineering manager of the General Electric Company's General Engineering Laboratory.

M. A. Edwards

Formerly associate engineer in charge of the laboratory's technical divisions, Dr. Edwards, in his new capacity, will be responsible for all engineering activities of the laboratory, and for engineering relations with other divisions and departments of the General Electric Company.

He is a native of Chautauqua, Kan., and holds four degrees from Kansas State University, including the bachelor degrees in electrical and mechanical engineering, awarded in 1928 and 1929, respectively, the mechanical engineering degree awarded in 1934, and an honorary Doctor of Science, conferred in 1946.

Dr. Edwards joined General Electric in 1929 as a student engineer on the test course. Upon completion of his first test assignment, he started work as an engineer with **Ernst F. W. Alexanderson** (A'13–M'13–F15) on television and related transmission problems. In 1945, he was appointed division engineer, controls system division of the former General Engineering and Consulting Laboratory, and in 1949 became associate engineer in charge of the laboratory's technical divisions.

Dr. Edwards holds 82 patents for ideas developed in the field of industrial controls, and has nearly an equal number of patents pending. His first patent was granted in 1934, for a follow-up system of ordnance control used in positioning of naval guns.

Among his accomplishments during World War II are work on development of aircraft gun turrets for bombers, on application of electric drive units for tanks, on controls for turbo-superchargers, on radar equipment, and on application of certain devices for navy ordnance.

During his 22 years with General Electric, Dr. Edwards has been a three-time winner of the Coffin award, the company's highest honor to an employee for outstanding achievement. The first of these was awarded for his work on equipment known as synchronous torque amplifiers for marine applications, the second for his share in devising extremely sensitive and powerful systems of amplification and automatic control for high-speed electric machinery, and the third for his ingenuity and persistent effort while collaborating on the development of gas-turbine accessories for the armed services during World War II.

In 1941, he received an award from the American Institute of Electrical Engineers for an outstanding paper entitled, "Industrial Applications of Amplidyne," of which he was co-author.

He is a Fellow of the American Institute of Electrical Engineers, and belongs to the Army Ordnance Association and to the American Association for the Advancement of Science.

❖

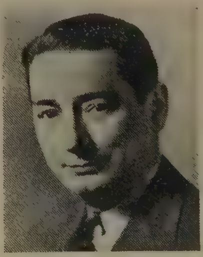
F. L. Hopper (A'26–SM'44), formerly associated with the electrical research products division of Western Electric until its activities in the sound-recording and broadcasting fields were terminated, has been transferred to the Western Electric Radio Shops at Winston-Salem, N.C.

He is now on loan to Bell Telephone Laboratories, and is concerned with various military electronic activities for the Armed Forces.

Mr. Hopper is a graduate of the California Institute of Technology, from which he received the B.S. degree in physics in 1922. He is a member of the Acoustical Society of America, and of the Society of Motion Picture and Television Engineers. The author of some 30 papers in the audio field concerning acoustics, instruments and sound recording, and broadcasting systems, Mr. Hopper has served on the IRE Electroacoustics Committee, and is currently a member of the Audio Techniques and the Sound Recording and Reproducing Committees of the Institute.

❖

D. W. Gunn (M'47) has been named equipment sales manager of the radio and television division of Sylvania Electric Products Inc., according to a recent announcement.



D. W. Gunn

Formerly assistant to the general sales manager, he will now be responsible for administering the equipment sales organization. He will also supervise and direct activities of the Sylvania district offices throughout the entire country.

Mr. Gunn has had wide experience in the field of quality control, and through his contacts with receiver and equipment manufacturers, he is well versed in problems related to tube applications. During World War II, he devoted much time to the standardization and testing on radar tube types in conjunction with various branches of government services.

Born in New York, N. Y., in 1907, Mr. Gunn received the B.E.E. degree from Northeastern University in 1929, whereupon he joined the Raytheon Manufacturing Company, Newton, Mass., as a production engineer. In 1932, as a factory engineer in the lamp division, he began his career with Sylvania Electric Products Inc.

Books

Survey of Modern Electronics by Paul G. Andres

Published (1950) by John Wiley & Sons, Inc., 440 Fourth Ave., New York, N. Y. 499 pages+20-page index+2-page appendix+x pages. 355 figures. 5½×8½. $5.75.

This survey is addressed to students of mechanical, chemical, and industrial engineering. The subject of electronics is, to such an audience, as important as it is difficult. In order to sustain the interest of the students, Mr. Andres has adopted an ingenious plan. After an introduction (Chapter 1) he takes up in succession the different kinds of tubes, evacuated or gas-filled (Chapters 2 to 7), and in each case the description of the tube is followed by some of its more immediate applications. Thus the industrial applications are never out of sight for long. In the four last chapters, Mr. Andres discusses electronics in instrumentation, in communications, electronic controls, and electronics in heating. Here we see how all the kinds of tubes previously described can be incorporated into a large single system to a specific end. The whole book is extremely readable, and the wide span of the field of electronics which is presented cannot fail to make a strong impression on the reader.

A difficulty common to all survey courses is to determine how deep one shall go into the subject. The present book will satisfy two classes of readers. The text is frankly descriptive and corresponds to a one-semester college course. The problems placed at the end of most chapters require a good deal more technical knowledge; they probably correspond to the level of a detailed two-semester course which the author has also been giving. An M.E. student who has gone through these problems will be quite solidly informed about electronics. The book will be equally valuable to older readers wishing to obtain broad and reliable information on the ever-increasing field of engineering electronics.

P. Le Corbeiller
Harvard University
Cambridge, Mass

Basic Electrical Measurements by Melville B. Stout

Published (1950) by Prentice-Hall, 70 Fifth Ave., New York, N. Y. 479 pages+9-page index+12-page appendix+viii pages. 255 figures. 5¾×8½. $7.75.

This book is written as an undergraduate text to prepare students for a proper understanding of the subject in its broader forms. It will also prove very useful as a handy reference book to many people in industry. A knowledge of simple ac circuit theory is naturally assumed. The author introduces Thevenin's theory as an aid to the understanding of unbalanced bridges.

The material included is not intended to be comprehensive, but rather to discuss the more commonly used methods in electrical measurements. For a book of this length, the selection is satisfactory and up to date. Of particular merit are the short discussions in Chapter 1 on the development of electrical units, and the excellent summary on errors in Chapter 2, where the author distinguishes clearly between accuracy and precision. The subject of errors is carried through the remainder of the text in evaluating the accuracy of various bridges, and so forth. However, the reviewer feels that even greater emphasis on the subject would not have been misplaced.

The subject matter covers resistance measurements, galvanometers, potentiometers, alternating current bridges, mutual inductance measurements, and shielded bridges. Alternating-current bridges cover impedance measurements up to 40 mc. A chapter on characteristics of bridge components discusses the construction of impedance standards, frequency errors, and so forth. Chapters on bridge accessories, instrument transformers, and magnetic measurements are also included. A final chapter of eighty pages covers the principles and practical forms of electrical indicating instruments. Most chapters have a good number of problems, and the figures are adequate and clear.

H. D. Doolittle
Machlett Laboratories, Inc.
Springdale, Conn.

Applied Nuclear Physics, Second Edition by Ernest Pollard and William L. Davidson

Published (1950) by John Wiley & Sons, Inc., 440 Fourth Ave., New York, N. Y. 281 pages+15-page index+53-page appendixes+ix pages. 90 figures. 6×9½. $5.00.

This is the second edition of a book which has been of considerable interest to a wide variety of workers in diverse fields, including chemistry, biology, and physiology, as well as physics. The reviewer finds this a most welcome book, as did the reviewer of the first edition. The authors have very successfully achieved a balanced, readable, and informative volume at an introductory level, which makes no pretext at being a reference book, but which does present, as the dust jacket claims, "an interesting and concise explanation of nuclear physics and its progress since 1942."

Chapter 1 surveys the role of the nucleus in atomic structure, and outlines some of the experiments which were instrumental in establishing the nature of the nucleus.

Chapter 2 discusses the properties of nuclear radiations and particles.

Chapter 3 surveys the various experimental methods for the detection of nuclear particles. Chapter 4 examines the methods of accelerating the atomic particles. Both of these chapters include a remarkable amount of information in a small space, and the reader will be reasonably familiar with the operating principles of much of the machinery of nuclear engineering after he has read them. Occasionally the writing is rather dramatic, particularly in the discussion of some newer, larger machines. But the cutaway sketch of the bevatron and its dimensions certainly provides the opportunity for such dramatic writing.

Chapter 5, entitled "Transmutation," introduces the essential features of nuclear chemistry, and discusses the general problems of the balance sheet of mass and energy, nuclear reactions in general, nuclear reactions induced by deuterons, by neutrons, by alpha particles, by protons, by radiation, and by mesons. The problems of absorption and scattering are also examined.

Certain of the important aspects of the theory of radioactive decay, the energy of the products of radioactive decay, and the modern picture of the nucleus to account for these decay particles appear in Chapter 6. Those who are interested in making actual measurements involving artificial radioactivity will find Chapter 7 quite rewarding. The methods of this chapter find application in Chapter 8, which contains a collection of illustrative tracer-type experiments, as well as experiments involving the biological effects of nuclear radiations.

Chapter 9 considers the topics relating to stable isotopes, their measurements with mass spectrographs, and their separation.

The remainder of the book, which discusses many aspects of nuclear fission is, perforce, a considerably revised account. Although the original text contained an historical account of nuclear fission, much of the conjecture has now been removed. Considerable detail has been added about the products of nuclear fission, the energies, and the masses.

Chapter 11 is new. It gives an account of nuclear chain reactions, and goes into some detail in dealing with the several types of nuclear reactors now in operation. Also included is a discussion of the future trends in pile design.

The final chapter gives a brief qualitative discussion of the principal ideas and theories of the nature of the nucleus, with an explanation of the concepts of nuclear forces.

A number of interesting and useful appendixes complete the book.

This reviewer agrees with the authors, ". . . that the account is sufficiently thorough to make this a useful textbook in a course on nuclear physics." Moreover, it provides a very interesting source for those who seek a readable account of a rapidly developing field.

Samuel Seely
Syracuse University
Syracuse, N. Y.

Correction

R. D. Teasdale has called to the attention of the editors certain typographical errors that were made in the publication of his review of the book, "Static and Dynamic Electricity (Second Edition)," by W. R. Smythe, on page 321 of the March, 1951, issue of the Proceedings. In particular, the end of the third paragraph should read:

". . . Many questions are from the Cambridge University examinations as reprinted from Jeans.[1]

With the possible exception of Weber's recent book,[2] the application . . . ."

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Prepared by the National Physical Laboratory, Teddington, England, Published by Arrangement with the Department of Scientific and Industrial Research, England, and *Wireless Engineer*, London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, and not to the IRE.

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ACOUSTICS AND AUDIO FREQUENCIES

534.232:534.321.9 **795**

An Ultrasonic Projector Design for a Wide Range of Research Applications—E. J. Fry. (*Rev. Sci. Instr.*, vol. 21, pp. 940–941; November, 1950.) Description of equipment providing simple means of changing from one thickness-mode crystal to another of different frequency.

534.321.9:534.231 **796**

The Determination of Ultrasonic Fields in Fluids—R. Krause. (*Z. angew. Phys.*, vol. 2, pp. 370–373; September 15, 1950.) Axial and transverse field patterns were investigated for a quartz radiator of diameter 3 cm using a quartz detector of diameter 3 mm. The radiator operated at 1 mc, emitting pulses of duration 1.6×10^{-5} to 3×10^{-4} sec. Measurements of the field along the axis are in good general agreement with calculated values based on Rayleigh's velocity-potential integral if due account is taken in the calculation of the damping effect of the radiator support. Discrepancies in the immediate neighborhood of the radiator are due to the finite transverse dimensions of the detector. The importance of the interference field is demonstrated; it may give rise to local vibration pressures several times as great as would be expected from simple consideration of total power radiated.

534.321.9:534.511.1 **797**

Satellite Resonances in Ultrasonic Interferometry—J. F. W. Bell. (*Proc. Phys. Soc.* (London), vol. 63, pp. 958–964; November 1, 1950.) Satellite resonances of the gas in the tube of an ultrasonic interferometer are identified as mode resonances and are of the type described by Rayleigh. The presence of unresolved satellites in the principal interferometer resonance introduces a considerable error into absorption measurements. Results obtained by van Itterbeek and his co-workers (4186 of 1937) are shown to be in agreement with the Krasnushkin interferometer theory (2914 of 1944), which takes account of the effect of the multiple nature of the principal resonance. A criterion for the choice of crystals for ultrasonic absorption measurements is given.

The Annual Index to these Abstracts and References, covering those published in the PROC. I.R.E. from February, 1950, through January, 1951, may be obtained for 2s.8d. postage included from the *Wireless Engineer*, Dorset House, Stamford St., London S. E., England. This index includes a list of the journals abstracted together with the addresses of their publishers.

534.321.9:534.613 **798**

A Method for the Measurement of the Sound Radiation Pressure in Ultrasonic Waves—H. Goetz. (*Z. Naturf.*, vol. 4a, pp. 587–588; November, 1949.) The pressure is estimated from the observed deflection of small air bubbles ascending in a trough of paraffin in which a 4.2-mc quartz generator transmits horizontally.

534.6 **799**

Note on the Definition of Complex Noise with Continuous Spectrum—P. Chavasse and R. Lehmann. (*Ann. Télécommun.*, vol. 5, pp. 375–377; November, 1950.) Reasons are given for preferring a "white" noise to a pure or wobbled tone as a source for acoustic measurements. The spectral curves obtained with such a source will differ according as the analysis is performed with a device in which $\Delta f/f$ is constant or one in which Δf is constant; hence it is important that the type of analyzer used should be clearly indicated.

534.84 **800**

Vibrations of Enclosed Spaces with Deformable Elastic Boundaries—T. Vogel. (*Ann. Télécommun.*, vol. 5, pp. 378–380; November, 1950.)

534.846 **801**

Relation between Architectural and Microphone Acoustics—J. Bernhart. (*Ann. Télécommun.*, vol. 5, pp. 338–346; October, 1950). The concept of reverberation time is by itself insufficient to define the acoustic characteristics of a studio when a microphone is used for sound pickup. Apparent reverberation is greater and variations in tonal quality are sharper. Parameters which may be considered in this case are discussed, especially acoustic perspective, the notion of "sound planes," and the sound-source-microphone couple. Quality of reverberation varies according to the disposition of this couple. The influence of room contours and distribution of absorbing and reflecting surfaces on apparent reverberation are studied for certain experimental studios.

534.846 **802**

Acoustics of London's New Concert Hall—(*Audio Eng.*, vol. 34, pp. 26, 64; November, 1950.) A brief discussion of the architectural plan of the South Bank Concert Hall. Variations from usual practice have been introduced in the arrangement of the orchestra to obtain acoustic improvements.

534.846 **803**

New Acoustic Theories—J. Moir. (*FM-TV*, vol. 10, pp. 29–30; November, 1950.) Experiments carried out in England indicate that the sound-decay pattern of a studio or hall is more important than the reverberation as a criterion of acoustic quality. Equipment is described with which a complete picture of the decay curve of the reverberant sound resulting from an initial tone-pulse can be obtained, and typical curves are shown for auditoria with good and with poor acoustic quality. The particular features of various concert halls which contribute to their good acoustic properties are discussed.

534.85/.86:[621.396.645.029.3+621.395.623.] **804**

The FAS Audio System: Part 2—M. B. Sleeper. (*FM-TV*, vol. 10, pp. 31–34; November, 1950.) Details are given of the arrangement of the three loudspeakers used, and of the 3-way crossover network operating at 350 cps and 1200 cps, for which complete construction data are included. Best results are said to be obtained with the loudspeakers 5 to 10 feet apart. The bass loudspeaker is mounted near one end in the back wall of what is termed an air-coupler; this consists of a wooden box of dimensions about 6 feet × 16 inches × 6 inches (not critical), the walls being about 1 inch thick; an enclosed space between two floor joists will serve quite well. The resultant reproduction of the very-low-frequency notes of an orchestra, or the pedal notes of an organ, is surprisingly good. Part 1: 805 below.

534.85/.86:621.396.645.029.3 **805**

The FAS Audio System: Part 1—M. B. Sleeper. (*FM-TV*, vol. 10, pp. 22–24, 37; October, 1950.) Description of an amplifier and loudspeaker system designed to deliver sound-power output in about the same ratios as the outputs of the instruments used in broadcasting or in making a record. The relation between bass and treble is maintained at any level from full volume to bare audibility. The letters FAS stand both for the Fowler-Allison-Sleeper designs and for the Flewelling Audio System from which the designs here described were developed. Only three stages are used in the amplifier, with feedback from the secondary of the push-pull output transformer via a 30-kΩ resistor to the cathode of the first tube. Response is essentially flat from 20 cps to 20 kc, and this flat characteristic is maintained by the output transformer at any level up to its full power rating. Circuit details are given both for amplifier and its associated power-supply unit, which includes a double-Π filter to ensure a low hum level. The input stage has ample gain for a crystal pickup or a radio tuner, but the gain is insufficient for a reluctance pickup, which would require its own preamplifier. Part 2: 804 above.

534.85 **806**

Thorn Gramophone Needles—A. M. Pollock. (*Wireless World*, vol. 56, pp. 450–452; December, 1950.) Illustrations are given showing the wear of thorn points after use for different playing times. An extensive series of tests indicates that thorn needles under light loading (needle pressure about 14 gm) give very good reproduction and that the resulting record wear is negligible.

534.852:621.395.625.3 807

A Magnetic Record-Reproduce Head—M. Rettinger. (*Jour. Soc. Mot. Pic. Telev. Eng.*, vol. 55, pp. 377–390; October, 1950.) General principles of construction of a ring-shaped head, Type MI-10794, are discussed. Features of this head are: frequency range 30 cps–18 kc, high sensitivity, absence of microphonics, low bias-current requirements, and low hum level, due to its small size.

621.395.61.001.11 808

Electromechanical Couplings—F. A. Fischer. (*Frequenz*, vol. 4, pp. 262–267; October, 1950.) Laws governing the coupling of electrical and mechanical oscillatory systems are formulated, making use of the author's work on electromechanical transducers (552 of March and back reference).

621.395.623.7 809

Loudspeaker Cabinet Design—D. E. L. Shorter. (*Wireless World*, vol. 56, pp. 382–385 and 436–438; November and December, 1950.) The acoustical and electrical damping of loudspeakers fitted in closed cabinets is discussed, and experimental results obtained in the course of development work on loudspeaker cabinets during 1938–1947 are presented. Although the "infinite-baffle" type of cabinet of ample volume is often regarded as the ideal mounting, the full potentialities of such a system cannot always be realized in practice. The general characteristics of vented cabinets are described and details are given of the cabinet adopted for a 15-inch coaxial loudspeaker for BBC monitoring purposes. Performance data obtained with this combination indicate that a vented cabinet is capable of doing justice to the best loudspeaker units at present available.

621.395.625.3 810

Accidental Printing in Magnetic Recording—E. D. Daniel and P. E. Axon. (*BBC Quart.*, vol. 5, pp. 241–256; Winter, 1950–1951.) The weak fields produced by portions of a magnetic tape influence adjacent portions, so that spurious signals may occur in reproduction The extent of the effect and its dependence on various parameters are investigated theoretically and experimentally, together with methods of reducing the ratio of unwanted to wanted signals. The level of accidental printing depends on the original recorded intensity and wavelength, and on the separation between adjacent layers of film. Storage temperature should be low. The time-decrease of spurious signal is important, and high-frequency partial erasure on replay may be useful.

621.395.625.3 811

Magnetic Recording of Sound—F. Gallet. (*Onde élect.*, vol. 30, pp. 449–457; November, 1950.) General survey of present-day practice and equipment, and discussion of problems encountered, mainly with reference to magnetic-tape high-fidelity apparatus for broadcasting; other methods and equipment are mentioned briefly.

ANTENNAS AND TRANSMISSION LINES

621.392.09 812

Surface Waves and their Application to Transmission Lines—G. Goubau. (*Jour. Appl. Phys.*, vol. 21, pp. 1119–1128; November, 1950.) Two types of non-radiating surface wave on a wire are discussed theoretically. The first (discussed by Sommerfeld in 1899) is guided by a wire of finite conductivity; it exhibits an attenuation much less than that of a wave in a conventional guide or coaxial cable but the spatial extension of its field is very large. This type of guided wave would only be practically useful at frequencies above 3,000 mc.

The second type of wave is guided by a conductor whose surface is coated with a cielectric or threaded in order to reduce the phase velocity. Although this guide has greater losses than the Sommerfeld wire, its field is much more confined, and it becomes practicable above 100 mc. Waves may be launched on to the conductor from a coaxial cable by a horn. Experiment shows agreement with the theoretical losses. See also 281 of March.

621.392.26†:621.3.09 813

The Stability and Attenuation of Guided Electric and Magnetic Waves of the Same Critical Frequency—R. Müller. (*Z. Naturf.*, vol. 4a, pp. 218–224; June, 1949.) The calculation of waves in an infinitely long perfectly conducting guide is reduced to a two-dimensional boundary-value problem, whose many solutions include the electric (E) and magnetic (H) modes. E and H modes with the same critical frequency correspond to a multiple eigenvalue. Attenuation due to finite conductivity is treated as a perturbation, whose calculation also enables the case of degeneracy to be considered consistently. In general, the degenerate eigenvalue corresponds to linear combinations of E and H modes, these combinations representing the stable modes to which an attenuation constant can be assigned in an actual waveguide. Important examples of degenerate modes are discussed; the E_{1n} and H_{0n} modes in circular-section guides remain stable when attenuation is taken into account, whereas the E_{1m} and H_{1m} modes in rectangular guides become unstable except when the rectangle becomes a square.

621.392.26†:621.392.5.001.11 814

The Application of Quadripole Theory to Waveguide Systems—F. W. Gundlach. (*Arch. elekt. Übertragung*, vol. 4, pp. 342–348; September, 1950.) Quadripole theory can be applied to waveguide systems without regard to particular values of current, voltage or characteristic impedance. The discussion considers only the concepts of field impedance (ratio of transverse electric field to transverse magnetic field), phase difference between input and output planes, and efficiency. Simple relations are derived, capable of representation by circle diagrams.

621.392.26†:621.396.67 815

Slotted Waveguides and their Applications as Aerials: Experimental Study—J. Ortusi and G. Boissinot. (*Ann. Radioélect.*, vol. 5, pp. 308–320; October, 1950.) Results are reported of measurements made on guides with single and multiple slots to verify the theory presented in the first part of the paper (2129 of 1950). The modification of the reflection factor for a single slot observed in the case of an array is assumed to be due to wave circulating between adjacent slots. This concept is more complex than the classical one of impedance in an equivalent line, but simplifies physical interpretation of the propagation phenomena and prediction of performance within the pass band. Requirements are discussed for a slotted guide to give a specified performance as an antenna. To obtain a wide pass band, a structure combining several guides is necessary. Compared with the paraboloid-sector antenna, the waveguide structures are smaller and easier to rotate.

621.392.26†:621.396.67 816

Radiation of a Dipole inside a Waveguide of Rectangular Cross-Section—T. Vellat. (*Bull. schweiz. elektrotech. Ver.*, vol. 40, pp. 860–869; October 29, 1949. In German.) The radiation can be calculated by applying the principle of electrical reflection and using integrals of Hankel functions. The waves radiated are plane although the source is cylindrical. The influence of the radiating body extends uniformly over the whole section. This is of great practical importance, because dipole devices, which are mechanically simple, can therefore be used for emitting, collecting and controlling the radiation. Dielectric pins are used for matching to antennas, detectors, and the like.

621.392.5 817

Radiation Resistance of Skew-Wire Radio-Frequency Transmission Lines—S. S. Banerjee and R. R. Mehrotra. (*Indian Jour. Phys.*, vol. 23, pp. 403–409; September, 1949.) A general formula, applicable for any orientation of the lines with respect to each other, is derived and applied to six special cases of practical interest. Results for one of these cases were confirmed experimentally.

621.396.67 818

Ice Formation on Aerials—F. D. Bolt. (*BBC Quart.*, vol. 5, no. 4, pp. 236–240; Winter, 1950–1951.) The method of formation, effect, and removal of frost and "glaze ice" are discussed. With standing-wave antenna arrays the added weight of glaze ice may be many times the weight of the antennas themselves, so that serious damage may be caused unless the antennas were originally designed to withstand heavy loading. In the case of television antennas the change of antenna impedance due to a coating of ice may result in the formation of ghost images on receiver screens, owing to mismatch between the transmitting antenna and its feeder. To prevent ice formation on the folded dipoles of the Sutton Coldfield transmitter, heater elements providing 7.5 kw for each dipole are switched on when the temperature at the top of the antenna mast falls to 3°C.

621.396.67 819

The Theory of Receiving Aerials—J. Grosskopf. (*Frequenz*, vol. 4, pp. 249–261; October, 1950.) The limits of applicability of transmission-line theory to nonrectilinear antenna arrangements are discussed, and a theory is developed for circular and rhombic receiving antennas with nonstationary current distribution. Even for frame antennas of small size, slight departures from previously accepted theory manifest themselves as a dipole effect. Other common nonrectilinear arrangements, in particular asymmetrical ones, are also considered.

621.396.67 820

Diffraction by Paraboloids of Revolution—J. Ortusi and J. C. Simon. (*Ann. Radioélect.*, vol. 5, pp. 321–330; October, 1950.) Analogies between the properties of cm and light waves are discussed, and the Huyghens-Kottler formulas are applied to the determination of the field near the focus of a paraboloid of revolution. Results of measurements made at a wavelength of 8 cm with three different paraboloids, using a crystal detector, are in good agreement with the theory and indicate that, using the field of the geometrically reflected wave as source, the Huyghens-Kottler formulas are valid for exact calculations even when the dimensions of the diffracting element are of the order of 10λ. Axial gain and the possibilities of controlling beam direction by displacing the source are investigated.

621.396.67 821

Theory of Axially Slitted Circular and Elliptic Cylinder Antennas—D. R. Rhodes. (*Jour. Appl. Phys.*, vol. 21, pp. 1181–1188; November, 1950.) Application of Sommerfeld's method to the diffraction of a plane wave with arbitrary angle of incidence and polarization by perfectly conducting cylinders of infinite length having a slot parallel to the axis. The case of a slot of infinitesimal width (or slit) is considered in detail and the operation of a slitted cylinder as a traveling-wave system is analyzed. Radiation patterns for a cylinder with a single slit and with two diametrically opposite slits are given.

621.396.67 822

Approximate Method of Deriving the Standing Wave Ratio Produced by an Aerial

Array—T. C. Cheston. (*Marconi Rev.*, vol. 13, pp. 168–174; 4th Quarter, 1950.) The array is one in which a large number of radiating elements are distributed along a feeder, and the method is based on an analysis of the vector diagram of the reflections, along the feeder, from successive elements. The errors introduced by the assumption that the array is infinitely long are assessed.

621.396.67 823
New Communications Antenna—M. W. Scheldorf. (*FM-TV*, vol. 10, pp. 14–15; September, 1950.) The Andrew Type-3,000 antennas for communication in the ranges 148–162 mc and 162–174 mc are designed to provide a circular horizontal pattern, high gain, low number of feed points, low wind loading, and negligible coupling to the mast. An array of eight folded dipoles is used; the feed harness and method of stacking are described in detail. Performance measurements are shown in diagrams.

621.396.677 824
Microwave Antennas—J. Racker. (*Radio & Telev. News, Radio-Electronic Eng. Suppl.*, vol. 15; pp. 15A–17A, 31A; October, 1950.) Directivity and gain of parabolic, horn, and lens antennas are among the factors discussed. Suitable methods of excitation and types of transmission-line feeder are also briefly considered.

621.396.679.4 825
Aerial Feeder Connections—W. T. Cocking. (*Wireless World*, vol. 56, pp. 426–428; December, 1950.) Practical consideration of the coupling of a dipole to an unbalanced receiver circuit by either a balanced line or a coaxial cable. The efficiency of various systems in providing signal transfer, impedance match, balance and rejection of interference is discussed. Particular attention is devoted to a "balun" circuit which embodies two inductors and two capacitors and avoids the need for a screened transformer.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.012.3 826
Use of Conductance, or G, Curves for Pentode-Circuit Design—K. A. Pullen. (*Tele-Tech*, vol. 9, pp. 38–40, 45; November, 1950.) Sets of curves applicable to Type 7E7 tubes are shown and their use in circuit design is explained. See also 292 of 1950.

621.314.2 827
Developments in Small Chokes and Power Transformers—(*Electronic Eng.* (London), vol. 22, pp. 450–453; November, 1950.) Transformers used in Naval Service from 1936 to 1949 are described briefly, and the latest design in detail. This transformer is oil-filled, its terminal seals are made of fused aluminium oxide, and its case is deep drawn in two parts. C-type cores are used; these have several advantages over orthodox silicon-iron stampings. This type of transformer is the only one to qualify fully as an inter-Service standard type.

621.314.22.015.7 828
A Method for Designing Pulse Transformers—H. S. Kirschbaum and C. E. Warren. (*Trans. AIEE*, vol. 68, Part II, pp. 971–978; 1949.) Description of a method that takes account of transformer terminating impedances and permits control of certain features of the output wave form. The design relations give a clear indication of the possibility of realizing a design for a given set of specifications and, in many cases, provide several alternative designs to meet special requirements.

621.314.3† 829
The Dynamoelectric Amplifier: Class-A Operation—R. M. Saunders. (*Trans. AIEE*, vol. 68, part II, pp. 1368–1373; 1949.) Various dynamoelectric amplifiers are compared with the electronic amplifier, and the static and dynamic characteristics of both the single- and 2-stage dynamoelectric amplifiers are discussed from the ac steady-state point of view. The dynamic characteristics are calculated from equivalent circuits and compared with test results in the form of frequency-response and phase-angle curves. Negative-feedback circuits and response curves are also presented and the effects of feedback are noted. See also 46 of February.

621.314.3† 830
Self-Saturation in Magnetic Amplifiers—W. J. Dornhoefer. (*Trans. AIEE*, vol. 68, part II, pp. 835–846; 1949. Discussion, pp. 846–850.) Full paper. Summary abstracted in 565 of 1950.

621.316.8:621.396.822:621.317.7 831
The Measurement of Noise in Resistors—Oakes. (*See* 945).

621.319.4 832
Power Capacitors with Ceramic Dielectric—J. Peyssou. (*Ann. Radioélect.*, vol. 5, pp. 391–406; October, 1950.) The influence of the pottery industry is seen in the general adoption of dish and pot shapes for ceramic-dielectric capacitors. Design is discussed in relation to performance, viz., specified capacitance, operating voltage, maximum high-frequency power, and field strength. Heating during operation is studied, particularly heating due to the Joule effects in the electrodes; this can be reduced by the use of suitable types of connector. Brief descriptions are included of equipment and methods for the measurement of maximum reactive power and maximum high-frequency field strength.

621.392.43 833
Transformation of an Arbitrary Complex Impedance to a Given Resistance by means of a H.F. Line Section—P. Maurer. (*Arch. elekt. Übertragung*, vol. 4, pp. 349–352; September, 1950.) Coaxial-line sections are commonly used for matching a load to a generator in the dm-wave band, stubs being most often used. In many cases the problem can be simply solved by using a single coaxial-line section of appropriate length and characteristic impedance. Formulas for such sections are derived from basic equations of current and voltage distribution and are represented in polar diagrams. The sections are assumed lossless.

621.392.5 834
Circuit Analysis of Linear Varying-Parameter Networks—L. A. Zadeh. (*Jour. Appl. Phys.*, vol. 21, pp. 1171–1177; November, 1950.) Theory is presented which is essentially a generalization of the familiar frequency-domain theory of fixed linear networks. Such basic concepts as impedance, admittance, gain, and the like, are extended to linear varying-parameter networks and their important properties are outlined. Extensions are given also of the general mesh and node equations, Thévenin's theorem, dualization, and some other relations that hold in the case of fixed networks. Many theorems, properties, and relations that hold in the case of fixed networks may be extended with proper modifications to linear varying-parameter networks.

621.392.5:621.315.212 835
Attenuation and Delay Equalizers for Coaxial Lines—W. R. Lundry. (*Trans. AIEE*, vol. 68, part II, pp. 1174–1179; 1949. Full paper. Summary abstracted in 1619 of 1950.

621.392.5:621.315.212:621.397.743 836
Equalization of Coaxial Lines—K. E. Gould. (*Trans. AIEE*, vol. 68, Part II, pp. 1187–1192; 1949.) Full paper. Summary abstracted in 2152 of 1950.

621.392.6 837
Generalized Network Theory—U. Kirschner. (*Arch. elekt. Übertragung*, vol. 4, pp. 367–373; September, 1950.) By means of the "oriented path complex," the circuit equations are derived for a generalized network with r degrees of freedom, i.e., with r independent circuits. The equations are solved by means of Cramer's rule, leading to a determination first of the iterative matrix of a $2r$-pole, and finally, by splitting off and eliminating $(r-k)$ columns and rows, of the iterative matrix of a $2k$-pole $(k<r)$.

621.395.669.3 838
A Simple Crackle Eliminator using Selenium Rectifiers as Amplitude Limiters—K. H. Werner. (*Arch. elekt. Übertragung*, vol. 4, pp. 374–376; September, 1950.) In the characteristic of the Se rectifier the transition from the high-resistance to the low-resistance condition is so located that the rectifier requires no bias when used in a low-voltage limiter. Overload protection is also unnecessary. Extremely simple limiter circuits are thus possible, comprising merely capacitors and rectifiers. Rectifiers of different sizes were investigated; measurements are reported and discussed.

621.396.6 839
The Design of Electronic Equipment using Subminiature Components—M. L. Miller. *Proc. IRE* (Australia), vol. 11, pp. 284–289; November, 1950.) Reprint. See 1372 of 1950.

621.396.6 840
Proceedings, Symposium on Improved Quality Electronic Components—(*Tech. Bull. Nat. Bur. Stand.*, vol. 34, p. 151; October, 1950.) Fifty-two papers were presented at this conference, held in May, 1950, and sponsored by the American Institute of Electrical Engineers, The Institute of Radio Engineers, and the Radio Manufacturers' Association, with cooperation of U. S. Government departments. Copies of the *Proceedings* are available from the Trielectro Company, 1 Thomas Circle, Washington 5, D. C., at $3.50.

621.396.611.4:621.317.352 841
Simple Method for Measurement of Variations of Damping of Centimetre Waves—E. M. Philipp. (*Acta phys. austriaca*, vol. 2, pp. 239–244; February, 1949.) Description of a method applicable to cavity resonators. The quasi-stationary-oscillatory-circuit method commonly used for measurement of voltage resonance is adapted to the usw range. The limits of validity of the method are discussed.

621.396.615 842
The Generation of Oscillations in a Phase-Shift Oscillator—W. Taeger. (*Funk u. Ton*, vol. 4, pp. 525–530; October, 1950.) Mathematical analysis of the oscillatory condition in a circuit with an even number of identical stages and a Wien-bridge feedback link. See also 597 of March.

621.396.615.015.7† 843
Pulse Generator of Fixed Repetition Rate—F. A. Benson and R. M. Pearson. (*Wireless Eng.*, vol. 27, pp. 285–288; December, 1950.) A very simple circuit for producing short pulses from an ac source (about 200 v rms) is described and its operation analyzed. Negative pulses with an amplitude of about 60 v and a rise time <1 μs are obtained. The pulse repetition rate is identical with the frequency of the ac source.

621.396.615.14 844
Short-Wave Self-Oscillator Circuits—E. Green. (*Marconi Rev.*, vol. 13, pp. 135–152; 4th Quarter, 1950.) The circuits considered are those based on pairs of triodes with the cathodes, anodes or grids connected, and the single-tube equivalents with one electrode earthed. It is shown how the values of the external circuit components combine with the interelectrode capacitances to produce conditions for oscillation, and how losses in the grid circuit can be compensated.

621.396.645 845

The Grounded Grid Amplifier—J. Roorda. (*Electronic Eng.* (London), vol. 22, pp. 478–480; November, 1950.) A mathematical analysis of the essential characteristics of the grounded-grid triode used as a high-frequency linear amplifier, interelectrode capacitances being taken into account. Conditions for resonance and stability are discussed. Formulas are deduced for input admittance and voltage amplification.

621.396.645 846

Cathode-Follower Performance—A. J. Shimmins. (*Wireless Eng.*, vol. 27, pp. 289–293; December, 1950.) A mathematical analysis of the response of cathode-follower circuits to pulse and sawtooth signals. The distortion in practical circuits may be readily calculated.

621.396.645.015.7† 847

Pulse Amplifier for Fast Ionization Chambers and Proportional Counters.—(*Electronic Eng.* (London), vol. 22, p. 469; November, 1950.) AERE Specification 120 describes a 2-unit pulse amplifier, Type 1049B, particularly suitable for coincidence work and counting in the presence of a high background level. Full details can be obtained on request from the Atomic Energy Research Establishment, Harwell, Berkshire.

621.396.645.35 848

D.C. Amplifier for Biological Application—P. O. Bishop and E. J. Harris. (*Rev. Sci. Instr.*, vol. 21, p. 904; November, 1950.) Corrections to article abstracted in 2174 of 1950.

621.396.645.35 849

Wide-Band D.C. Amplifier Stabilized for Gain and for Zero—A. J. Williams, Jr., W. G. Amey, and W. McAdam. (*Trans. AIEE*, vol. 68, part II, pp. 811–815. Discussion, p. 815; 1949.) Full paper. Summary abstracted in 598 of 1950.

621.396.645.372 850

Positive Feedback in A.F. Amplifiers—C. H. Banthorpe. (*Electronic Eng.* (London), vol. 22, p. 473; November, 1950.) Positive feedback can be used to compensate for loss of gain due to negative feedback. An application of this principle in the audio-frequency stages of a broadcasting receiver is described.

621.319.4 851

Bauelemente der Nachrichtentechnik. Teil 1: Kodensatoren. [Book Review]—H. Nottebrock. Publishers: Schiele & Schön, Berlin, 172 pp., 9 D.M., 1949. (*Bull schweiz. elektrotech. Ver.*, vol. 40, p. 880; October 29, 1949. In French.) Gives practical information useful in selecting capacitors for telecommunications applications. The manufacture and properties of the various types, grouped according to dielectric, are described. Tests and test gear and performance in various circuits are discussed briefly.

GENERAL PHYSICS

537.523.4 852

Voltage Gradients in High-Current Spark Channels—J. E. Allen. (*Research*, (London), vol. 3, pp. 527–528; November, 1950.) Using an impulse generator producing peak currents up to 500 ka, oscillographic measurements of voltage drop across short spark-channels were observed for several gap widths. In the range 188–265 ka, voltage gradients were high and increased with current. The effect on the discharge of metal vapor from the electrodes was appreciable.

537.525:538.56 853

Free Spherical Electromagnetic Oscillations in Spaces containing Plasma—W. O. Schumann. (*Z. Naturf.*, vol. 4a, pp. 486–491; October, 1949.) Mathematical analysis is given for the following cases: a conducting plasma-filled sphere; a dielectric and a conducting sphere immersed in plasma; a plasma sphere in air. The effect of the frequency-dependence of the dielectric constant on the oscillation processes is discussed, and in particular the possibility of new modes of oscillation resulting from negative values of dielectric constant.

537.533.7:621.385.029.63/.64 854

Dynamic Electron Fow under the Influence of Dynamic Fields—H. W. König. (*Acta phys. austriaca*, vol. 2, pp. 312–334; February, 1949.) A plane electron flow is subjected to an electrical control field arranged in *n* sections, the control current in each section having the same amplitude. The phases are so chosen that the current in any section lags behind that in the previous section by an amount corresponding to the time taken by the electrons to traverse the section. In the limiting case a dynamic control field is obtained which moves at each point with the velocity of the electrons. In this case the field and velocity distributions are given by the same equations as for quasistationary flow, when account is taken of the phase lag in the periodic terms due to the finite value of the transit angle. The alternating field strength produced in the electron stream by the action of the control field increases in the case of the quasistationary field as the first power of the transit angle, but, on the other hand, as the square of the angle in the case of the dynamic field. In consequence, for equal transit angles, a considerably greater amplification can be obtained with dynamic control of the electron velocity. Since the noise characteristics are about the same in both cases, the limiting sensitivity is appreciably improved. Diagrams are given showing the field and velocity distributions for the case in which the electrons in the control path move with constant velocity. Application of the theory to the traveling-wave tube is outlined.

538.221 855

Studies of the Propagation Velocity of a Ferromagnetic Domain Boundary—H. J. Williams, W. Shockley, and C. Kittel. (*Phys. Rev.*, vol. 80, pp. 1090–1094; December 15, 1950.) Experimental results are given for the velocity of propagation of a single domain boundary in a crystal of silicon-iron with a simple domain structure. The results are discussed with reference to the eddy-current anomaly for ferromagnetic materials.

538.311 856

The Magnetic Field of a Plane Circular Loop—C. L. Bartberger. (*Jour. Appl. Phys.*, vol. 21, pp. 1108–1114; November, 1950.) "The axial and radial components of the magnetic field of a plane circular loop are expressed in terms of cylindrical co-ordinates. The expressions involve two integrals which are related to certain of the complete elliptic integrals. Tables of values of these integrals are presented. Interpolation in these tables facilitates rapid calculation of the field components."

538.566.2 857

Research on the Propagation of Sinusoidal Electromagnetic Waves in Stratified Media: Application to Thin Layers: Part 1—F. Abelès. (*Ann. Phys.* (Paris), vol. 5, pp. 596–640; September-October, 1950.) This paper deals with stratified systems in general; the second part is to deal with homogeneous thin layers. The essence of the method is, starting from Maxwell's equations, to represent stratified media having any values of dielectric constant and magnetic permeability by matrices with two rows and two columns. This facilitates consideration of discontinuous stratification. A method is developed for integrating differential field equations without restriction on the laws of variation of the characteristic parameters of the medium. General expressions are given for the coefficients of reflection and transmission and the corresponding phase shifts suffered by the field vectors, two cases of particular practical importance being treated in detail. The first is that where the thickness of the medium is small in relation to the wavelength of the incident waves. The second corresponds to a medium of any thickness where the variations of the parameters are very slow, as for example with a slightly inhomogeneous thin layer. Some general theorems on stratified media are proved, and the development of the general theory from that for an infinite stack of infinitely thin homogeneous layers is indicated. Analogies with other problems of physics and mechanics are discussed. A convenient method is described for studying media whose parameters are periodic in space.

538.566.2 858

Artificial Field Equations for a Region where μ and ϵ Vary with position—P. D. P. Smith. (*Jour. Appl. Phys.*, vol. 21, pp. 1140–1149; November, 1950.) Mathematical treatment of waves in a continuously variable medium is given which is similar to that used by Weyl for the relativistic effect of gravitational potential. The *TE* and *TM* cases are considered and also the fields derived from a 4-potential. Application of the method in cylindrical co-ordinates is used to derive formulas for the *TE*, *TM*, and *TEM* waves. Solutions are derived for specific distributions of μ and ϵ, with applications to curved guides, horns and coaxial lines.

538 859

Electromagnetic Fields: Theory and Applications. Vol. 1—Mapping of Fields. [Book Review]—E. Weber, Publishers: John Wiley and Sons, New York, N. Y., 590 pp., $10.00; 1950. (*Jour. Frank. Inst.*, vol. 250, pp. 586–587; December, 1950.) A comprehensive survey, with many examples illustrating the basic principles; it presents clearly the relations between analytical, experimental, graphical, and numerical methods of solving static-field problems. Recommended as a textbook for a degree course and as a reference work.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.72:621.396.822 860

The Polarization of Thermal 'Solar Noise' and a Determination of the Sun's General Magnetic Field—S. F. Smerd. (*Aust. Jour Sci. Res., Ser. A*, vol. 3, pp. 265–273; June, 1950.) "The equation of transfer of radiation and the magneto-ionic theory are used to derive expressions for the degree of polarization of thermal 'solar noise' due to a general magnetic field of the sun. In particular, the net polarization of 600-mc radiation corresponding to the maximum phase of the eclipse of November 1, 1948, as seen from Melbourne, Victoria, Australia, is evaluated theoretically and compared with observational evidence. This leads to an upper limit of 11 gauss for the surface field strength at the solar poles at the time of observation."

523.72:621.396.822 861

Solar Radiation at 1200 Mc/s, 600 Mc/s, and 200 Mc/s—F. J. Lehany and D. E. Yabsley. (*Aust. Jour. Sci. Res., Ser. A*, vol. 3, p. 350; June, 1950.) Correction to paper abstracted in 616 of 1950.

523.745 862

The Physical Meaning of the Character Figures of Solar Phenomena—G. Righini and G. Godoli. (*Jour. Geophys. Res.*, vol. 55, pp. 415–422; December, 1950.) Character figures and areas of Ca-flocculi, bright and dark H_α-flocculi are compared for the period 1932–1949. The character figures appear to be a function of the areas only.

523.746 863

Current Interpretation of the Sunspot Phenomenon—W. Grotrian. (*Z. angew. Phys.*, vol. 2, pp. 376–390; September 15, 1950.) A comprehensive survey; test of a lecture delivered at Munich in March, 1950. Observations of fluctuations of both solar magnetic field and solar diameter are consistent with the 11-year period of the sunspot cycle, but further systematic observations over at least 22 years are needed to check the various theories.

523.746 "1950.07/.09" 864
Provisional Sunspot-Numbers for July to September, 1950—M. Waldmeier. (*Jour. Geophys. Res.*, vol. 55, p. 488; December, 1950.)

523.854:621.396.822 865
Galactic Radiation at Radio Frequencies: Part 2—The Discrete Sources—G. J. Stanley and C. B. Slee. (*Aust. Jour. Sci. Res. Ser. A*, vol. 3, pp. 234–250; June, 1950.) A description is given of the special techniques necessary in the observation of the very small differences in noise intensity between the discrete sources and the background continuum. The results of measurements of the position and angular width of the discrete sources are discussed, and the present known data are tabulated. Measurements of intensity within the 40–160 mc band, showed that for three sources intensity changed more rapidly with frequency than did the background noise, while for a fourth source it changed less rapidly. The short-period fluctuations in intensity of the source in Cygnus are discussed; evidence is presented which suggests that their origin is in the ionosphere rather than outside it. Part 1: 348 of March (Bolton and Westfold). Part 3: 866 below (Bolton and Westfold).

523.854:621.396.822 866
Galactic Radiation at Radio Frequencies: Part 3—Galactic Structure—J. G. Bolton and K. C. Westfold. (*Aust. Jour. Sci. Res., Ser. A*, vol. 3, pp. 251–264; June, 1950.) From radio-frequency observations it is deduced that the sun is situated in or near an arm of a spiral galaxy. The radio-frequency data are analyzed and optical evidence in favor of the spiral form is presented. The sense of rotation of the galaxy—that of the spiral unwinding—is in accordance with the theories of Lindblad and Milne. Part 2: 865 above (Stanley and Slee).

523.854:621.396.822 867
Survey of Galactic Radio-Noise at 200 Mc/s—C. W. Allen and C. S. Gum. (*Aust. Jour. Sci. Res., Ser. A*, vol. 3, pp. 224–233; June, 1950.) Using a Yagi antenna array of known sensitivity pattern, galactic radio-noise was measured at 200 mc during a systematic scanning of the whole sky south of declination 45°N. The measurements of intensity are expressed relative to the level at the galactic poles and are accurate to within about 20 per cent in most regions, with a probable error of 1° in location. After correction for the integration effect of the antenna pattern, contour plots of the distribution of the radiation were made. Galactic noise is suggested as a standard for measurements of solar noise.

532.517.4:551.510.5:621.396.11 868
Scattering of Electromagnetic Waves by Atmospheric Turbulence—(*See* 973.)

550.37:551.594.21 869
Thunderstorms and the Earth's General Electrification—O. H. Gish and G. R. Wait. (*Jour. Geophys. Res.*, vol. 55, pp. 473–484; December, 1950.) The conductivities and electric field strengths were measured above 21 thunderstorms. The conductivity was not altered appreciably by the presence of the storms. All storms showed a positive current flowing upwards, the total current ranging from 0 to 1.4a, with an isolated reading of 6.5a. The average value, omitting the latter high reading, was 0.5a. In ten cases the electric-field profile corresponded with that of a simple bipolar model. The observations support Wilson's hypothesis concerning the effect of thunderstorms in maintaining the earth's permanent negative charge.

550.38 "1950.04/.06" 870
International Data on Magnetic Disturbances, Second Quarter, 1950—J. Bartels and J. Veldkamp. (*Jour. Geophys. Res.*, vol. 55, pp. 485–487; December, 1950.)

550.38 "1950.07/.09" 871
Cheltenham [Maryland] Three-Hour-Range Indices *K* for July to September, 1950—R. R. Bodle. (*Jour. Geophys. Res.*, vol. 55, p. 488; December, 1950.)

550.384 872
Results on Geomagnetic *K*-Indices for the International Polar Year 1932–33—J. Bartels. (*Jour. Geophys. Res.*, vol. 55, pp. 427–435; December, 1950.)

550.385:551.594.52 873
The Southward Shift of the Auroral Zone during Intense Magnetic Storms—V. C. A. Ferraro. (*Jour. Geophys. Res.*, vol. 55, p. 493; December, 1950.) Comment on a paper by Nagata (2501 of 1950). The southward movement of the auroral zone in the northern hemisphere during severe magnetic storms can be explained by the theory of Chapman and Ferraro as well as by Störmer's original auroral theory.

550.385 "1950.04/09" 874
Principal Magnetic Storms [April–September, 1950]—(*Jour. Geophys. Res.*, vol. 55, pp. 489–492; December, 1950.)

551.510.52:[551.543+551.524.7 875
Day-to-Day Variations of Pressure and Temperature in the Lower Troposphere to 5-km Height, and their Mutual Statistical Synoptical Relations—H. Hoinkes. (*Arch. Met. Geophys. Bioklimatol.*, vol. 2, pp. 239–300; March 28, 1950. Bibliography, pp. 300–304.) Correlation of many thousands of observations at seventy stations in various parts of Europe, the North Atlantic, North Africa, Spitzbergen, and Inner Asia.

551.510.53:001.4 876
Upper Atmospheric Nomenclature—S. Chapman. (*Jour. Geophys. Res.*, vol. 55, No. 4, pp. 395–399; December, 1950. *Jour. Atmos. Terr. Phys.*, 1950, vol. 1, pp. 121–124.) Many new terms characterizing the various atmospheric regions and levels are suggested.

551.510.535+551.594.5 877
Corpuscular Influences Upon the Upper Atmosphere—S. Chapman. (*Jour. Geophys. Res.*, vol. 55, pp. 361–372; December, 1950.) A critical review of the evidence for and against the corpuscular theory of magnetic storms and auroras, including discussion of certain crucial tests and difficulties. The observed solar and terrestrial phenomena to be explained are examined in detail. It is concluded that the available data may be most readily interpreted in terms of the corpuscular theory. The most direct evidence for the theory is given by recent observations of the broadening of the hydrogen lines in the auroral spectrum.

551.510.535 878
The Lowest of the Ionized Layers of the Upper Atmosphere—D. Stranz. (*Tellus*, vol. 2, pp. 150–157; August, 1950.) Discussion of the properties of the *D* layer and of various theories of its formation.

551.510.535 879
Thermal Splitting of Ionosphere Layers—O. Burkard. (*Arch. Met. Geophys. Bioklimatol.*, vol. 2, pp. 308–314; March 28, 1950.) The rate of ion production is calculated as a function of height, assuming a stratified temperature distribution. Under certain conditions, such a distribution can give rise to two maxima of ionization. A similar process may account for the splitting of the ionosphere *F* layer during the day.

551.510.535 880
Prediction of Ionospheric Conditions for Antipodal Stations—G. R. White and R. F. Potter. (*Trans. Amer. Geophys. Union*, vol. 30, pp. 686–690; October, 1949.) For another account see 1660 of 1949.

551.510.535 881
Ionosphere over Calcutta—S. S. Baral and A. P. Mitra. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 95–105; 1950.) Records made at Calcutta during the solar half-cycle January, 1945–June, 1950, were analyzed in order to determine the following ionospheric parameters: rate of electron production, temperature, and effective coefficient of recombination. The value of the earth's magnetic field at the average height of the F_2 region was also determined. Graphs show the variations of the various quantities.

551.510.535 882
Studies of the F_2 Layer in the Ionosphere: Part 1—The Position of the Ionospheric Equator in the F_2 Layer—E. Appleton. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 106–113; 1950.) "The seasonal variations of the noon equivalent heights of the F_2 layer at a number of stations are examined and the variations characteristic of the northern hemisphere and of the southern hemisphere identified. It is shown that the changeover from one type of variation to the other occurs in a region which is more nearly coincident with the magnetic equator than with the geographical equator."

551.510.535 883
27-Day Variations in F_2-Layer Critical Frequencies at Huancayo—J. Bartels. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 2–12; 1950.) "The solar radiation responsible for the production of F_2-layer ionization is already known to change with the 11-year sunspot cycle. The question has therefore been examined whether analogous changes occur in the course of the solar rotation of about 27-days period in cases where the sunspot numbers *R* show appreciable quasi-persistent periodicities. After correcting for lunar tidal influence, variations of the type in question have been found in the noon values of fF_2 for Huancayo, Peru, using the superposed epoch method. Such variations are found to be of the order of 6 to 10 per cent. Changes in fF_2 accompanying changes in *R* appear to be delayed by about two days, but a scatter analysis by means of synchronized harmonic dials throws doubt on the statistical significance of such a lag. The lunar tides in the noon values of fF_2, examined for comparison, cause total semimensual changes of more than 10 per cent in southern summer, but only 2 to 3 per cent in southern winter. These seasonal changes in the lunar tidal effect $L(fF_2)$ are much larger than those disclosed in the quantitative effects of changes of *R* on fF_2. The use of these results in ionospheric forecasting is briefly discussed."

551.510.535:523.745 884
Comparison of Variously Derived Solar Indexes—H. S. Moore and M. Stein. (*Jour. Geophys. Res.*, vol. 55, pp. 423–425; December, 1950.) Values of the ionospheric solar-activity index S_I based on data from Washington, Huancayo, and Watheroo show slightly closer correlations with the noon values of f_0F_2 at other stations than do values of S_I based on Washington data only. The use of 27-day medians in place of monthly medians does not alter the correlation significantly. See also 727 of 1948 and 391 of 1949 (Phillips).

551.510.535:523.75 885
Observations of Solar and Terrestrial Phenomena during the Mögel-Dellinger Effect (S.I.D.) on 19th Nov. 1949—R. Müller: O. Augustin and W. Menzel: A. Ehmert: H. Salow: A. Sittkus: W. Dieminger and K. H. Geisweid: J. Bartels. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 37–48. 1950. In German.) The different authors report respectively on the fol-

lowing phenomena observed at stations in Germany during this sudden ionospheric disturbance: a solar flare of intensity 3; increases of 9.7–20 per cent of cosmic-ray intensity; a radio fadeout accompanied by an increase of the ionization in the E_1, E_2, and F_2 layers; and a terrestrial-magnetic solar-flare effect. See also 1911 of 1950 (Ellison and Conway), 2206 of 1950 (Müller), and 3039 of 1950 (Clay and Jongen).

551.510.535:523.78 "1947.05.20" 886

Recombination and Attachment in the F-Region during the Eclipse of May 20, 1947—J. Savitt. (*Jour. Geophys. Res.*, vol. 55, pp. 385–394; December, 1950.) Ionization densities at four heights in the F_2 region are deduced by Manning's method from data obtained during the eclipse at Bocayuva, Brazil. The results are compared with predictions based on simple recombination and attachment hypotheses. Neither hypothesis explains the data completely, the former being slightly better at the lesser heights and the latter at the greater. The better general agreement is obtained with the attachment hypothesis, the coefficient of attachment being consistent with attachment to neutral oxygen atoms. Both coefficients vary considerably with height, and the data indicate that the intensity of ionizing radiation may increase near sunspot groups.

551.510.535:535.34:621.396.11 887

Attenuation of the Extraordinary Component in the Ionosphere E₁ Layer—W. Becker. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 73–81; 1950. In German.) The experimental observation that no extraordinary-ray echoes can be received from the normal E layer around sunrise and sunset for frequencies between the gyrofrequency (1.39 mc) and about 2.5 mc, is in accordance with numerical considerations developed. The absence of these echoes is due to the high mean electron-collision frequency, which prevents the real part of the refractive index from reaching a value substantially below unity, a necessary condition for appreciable reflection. In the absence of these echoes, the extraordinary-ray critical frequency of the E_1 layer can be identified as the frequency at which the first echoes are received from a layer at a greater height.

551.510.535:535.34:621.396.11 888

The Absorption of Long and Very Long Waves in the Ionosphere—Stanley. (*See* 974.)

551.510.535:550.385 889

Investigation of the World-Wide Ionospheric Disturbance of 15th March 1948—O. Burkard. (*Arch. Met. Geophys. Bioklimatol*, vol. 2, pp. 315–324; March 28, 1950.) Observations at 30 stations were examined regarding the variations of the F_2-layer critical frequency on the occasion of the geomagnetic storm on the above date. A marked increase of the critical frequency was noted in low geomagnetic latitudes and a decrease in high latitudes. The progress of the main ionospheric disturbance appears to be related to local time.

551.510.535:621.396.812.2 890

A Study of the Horizontal Irregularities of the Ionosphere—Briggs and Phillips. (*See* 980.)

551.510.535:621.396.812.3 891

Periodic Fading of Short-Wave Radio Signals—Khastgir and Das. (*See* 981.)

551.577:621.396.9 892

Observation of Precipitation with an Airborne Radar—E. J. Smith. (*Aust. Jour. Sci. Res., Ser. A*, vol. 3, pp. 214–223; June, 1950.) Observations were made on a wavelength of 10 cm, using a radar set with its beam directed downwards from an aircraft. Photographic records were obtained of the intensity of the echoes from precipitation. A detailed description is given of observations made during the seeding of a cloud with "dry ice." Measurements of the area and duration of precipitation and estimates of precipitation rate below the freezing level and of snowflake size above it were obtained; the rate of fall of the disturbance was also measured. Ice crystals appear to form initially near the bottom of the cloud.

551.578:539.16 893

On the Radioactivity of Atmospheric Precipitates—A. Stefanizzi. (*Jour. Geophys. Res.*, vol. 55, pp. 373–378; December, 1950.)

551.594.12 894

The Ionization Balance of the Atmosphere—V. F. Hess and R. P. Vancour. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 13–25; 1950.) Methods for determining the contribution to the total atmospheric ionization made by α, β, and γ rays from radioactive substances in the ground and air and by cosmic rays are described, and results of measurements made at Fordham University, New York, are reported. The mean number of small ions is computed to be <100 per cm^3 in the stationary state, as is to be expected near a big city, where the number of condensation nuclei is usually $>40{,}000$ per cm^3.

LOCATION AND AIDS TO NAVIGATION

621.396.9:621.39.001.11 895

A Theory of Radar Information—P. M. Woodward and I. L. Davies. (*Phil. Mag.*, vol. 41, pp. 1001–1017; October, 1950.) "The theoretical accuracy and certainty with which range may be determined by radar is obtained quantitatively by applying the principle of inverse probability. In agreement with experience, the theory yields two fundamental criteria for satisfactory radar reception. First, the total received signal energy must always be larger than the effective noise power per unit bandwidth. Secondly, there is a more stringent threshold of unambiguous reception which depends not only on the quantity of received energy but also on the bandwidth of the transmitted wave form, for as this is increased the minimum energy required for the certain detection of an echo also increases. The quantity of information obtainable at the receiver, as measured by reduction of entropy, is evaluated for comparison with that given by Shannon's general theory of communication [1361 and 1649 of 1949]. It is found that as the time of observation and hence the received energy increases, information is initially obtained at a roughly uniform rate which is not far removed from the absolute limit for an ideal communication system, but that after crossing the threshold of unambiguous reception, additional received energy contributes little further information."

621.396.93 896

Instantaneous Direction Finding—J. Rhys Jones. (*Electronic Eng.* (England), vol. 22, pp. 481–482; November, 1950.) A historical account of the development of direction-finding equipment using cathode-ray tubes, with descriptions of a pre-war and a wartime model. See also 1064 of 1949 (de Walden, et al.).

621.396.933 897

The Development and Status of Radio Navigational Aids to Civil Aviation—R. M. Badenach and R. E. Gillman. (*Proc. IRE* (Australia), vol. 11, pp. 273–283; November, 1950.) The development of radio navigation aids prior to the second World War is described and the effect of that war on the problem is discussed. The present-day status of navigation aids in various countries throughout the world is reviewed. The work of ICAO in setting the standards for world-wide practice and performance is summarized and plans which have been produced to meet these requirements in the United States and Australia are outlined.

621.396.933:526.25 898

A Rigorous Method for Computing Geodetic Distance from Shoran Observations—C. W. Kroll. (*Trans. Amer. Geophys. Union*, vol. 30, pp. 1–4; February, 1949.) Certain assumptions are made and Anderson's 1941 value of 299, 776 km for the velocity of light is used. Accurate formulas are derived, but as computation from them is impractical, an approximate method of numerical integration was evolved. This has the advantage that it is an iteration process which can be carried out on an electronic computer in a few seconds.

621.396.933.23 899

Einstein's Equivalence Principle and the Problem of Blind Navigation—J. J. Gilvarry. (*Phys. Rev.*, vol. 73, pp. 1409–1410; June 1, 1948.)

621.396.933.23 900

Application of Liouville's Approximation to the Blind Navigation Problem—J. J. Gilvarry and S. H. Browne. (*Jour. Appl. Phys.*, vol. 21, pp. 1195–1196; November, 1950.)

621.396.933 901

Consol—a Radio Aid to Navigation (M.C.A.P. 59). [Book Notice]—Ministry of Civil Aviation. Publishers: H. M. Stationery Office, London, 2nd edn. 1950, 1s.6d.—(*Govt. Publ.* (London), p. 15; September and October, 1950.) Brief description of its use, with details of the service and cover provided by existing stations.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.37 902

The Behaviour of Phosphors and Photoconductors in Intense Electric Fields—E. Krautz. (*Z. Naturf.*, vol. 4a, pp. 284–296; July, 1949.) The transient enhancement of luminescence produced by applied fields was investigated experimentally for over 250 phosphors, at low temperature, using a specially constructed grating-type cell making field strengths up to 300 kv per cm possible. Oscillograms illustrating the decay of the luminescence after switching the field on or off are shown and discussed; from the shape of the curves it can be judged whether the reaction mechanism is monomolecular or bimolecular. The peak value of the luminescence flash depends on both field intensity and time interval after excitation of the phosphor (e.g., by X rays).

535.371 903

The Influence of Temperature on the Fluorescence of Solids—F. A. Kröger and W. de Groot. (*Philips Tech. Rev.*, vol. 12, pp. 6–14; July, 1950.) The theory of the mechanism of fluorescence is outlined and methods for measuring the relative efficiency of fluorescence and its rate of decay after excitation is cut off are described in detail. Results of measurements for simple cases are compared with deductions from the theory. Effects observed in more complex cases are discussed and examples are given of cases where the efficiency depends not only on temperature but also on the intensity of the incident radiation.

535.371:[546.321.41+546.341.61 904

The Decays of Luminescent KBr and LiF—A. H. Morrish and A. J. Dekker. (*Phys. Rev.*, vol. 80, pp. 1030–1034; December 15, 1950.) Photomultiplier investigation of luminescence decay after irradiation by X rays, at 21°C and at 0°C.

537.311.33 905

Controlled-Valency Semiconductors—E. J. W. Verwey, P. W. Haaijman, F. C. Romeijn and G. W. van Oosterhout. (*Philips Res. Rep.*, vol. 5, pp. 173–187; June, 1950.) "In inorganic solids of a more or less polar type (e.g., oxides) a condition for electronic conductivity is that the lattice contains ions derived from the same element but of different valency in the same crystallographic position. A new type of semiconductor is described in which this condition has been realized by the introduction of a fraction of ions of deviating valency without the simultaneous formation of lattice defects as in 'non stoichiometric' compounds. Such a situation is promoted by the incorporation into the lattice of foreign ions of such a charge that they balance the charge of the ions of deviating valency. Various examples are given and some of the properties of the materials thus obtained are described. Materials of this type have been applied, for instance, in ceramic resistors having a large negative temperature coefficient of the resistance. The influence of various impurities upon the specific resistance of poorly conducting substances or insulators with a crystal lattice of the polar type can also be understood along these lines."

537.311.33:537.311.1 **906**

Fermi Levels in Semiconductors—R. A. Hutner, E. S. Rittner and F. K. du Pré. (*Philips Res. Rep.*, vol. 5, pp. 188–204; June, 1950.) "General formulas for determining the Fermi level and the density of free charge carriers in semiconductors are derived. Special semiconductor models are considered in detail and a few applications are discussed."

537.311.33:621.315.592†:546.28.261 **907**

On the Mechanism of Impurity-Band Conduction in Semiconductors—C. Erginsoy. (*Phys. Rev.*, vol. 80, pp. 1104–1105; December 15, 1950.) The anomalous low-temperature effects on the resistivity and Hall coefficient of SiC are interpreted on the basis of a conduction mechanism in an impurity band formed by the interaction of the excited impurity states at high concentrations.

537.311.33.621.315.592†:621.396.645 **908**

The Amplification Observed in Semiconductors—Mataré. (*See* 1037.)

537.311.33:621.315.592:621.396.822 **909**

Statistical Fluctuations in Semiconductors—H. F. Mataré. (*Z. Naturf.*, vol. 4a, No. 4, pp. 275–283; July, 1949. *Jour. Phys. Radium*, vol. 10, pp. 364–372; December, 1949; vol. 11, pp. 130–140; March, 1950.) The analogy between barrier layer and diode is considered. An equivalent steady-state circuit is presented for a semiconductor rectifier, and the equivalent noise source and square of noise voltage are determined. The analytical representation of the barrier-layer noise temperature obtained from measurements on diodes and semiconductors is then introduced, and a practical law is derived for the square of the noise voltage, i.e., the statistical fluctuations.

537.311.33:621.315.592:621.396.822 **910**

A Theory of Contact Noise in Semiconductors—G. G. Macfarlane. (*Proc. Phys. Soc.* (London), vol. 63, pp. 807–814; October 1, 1950.) "A theory of contact noise is described in which the low-frequency noise is attributed to the random movement of adsorbed ions on the surface of a semiconductor from which an electron current is being drawn. Emission of electrons is assumed to take place only at localized patches on the surface and the adsorbed ions are assumed to give rise to a Schottky barrier layer, in which the potential maximum is linearly related to the concentration of ions. Diffusion of the ions over the surface gives rise to random fluctuations in the concentration of ions in a patch, which results in random fluctuations in the height of the potential barrier and the emission current. It is shown that for a circular patch the spectral power density of the noise current varies with mean current j_0 and frequency f as $j_0^2 f^x$ over a small range of frequency and that x varies monotonically from -0.75 at the lowest frequencies to -1.125 at the highest frequencies. It is also shown that for a long thin rectangular patch the index x varies monotonically from -0.5 to -1.5 as the frequency is increased from zero. The dependence of the noise power density on temperature is also discussed."

537.311.33:621.315.592.011.2† **911**

Effect of Isolated Lattice Irregularities on the Electrical Resistance of Electronic Semiconductors and its Temperature Dependence—W. Heywang. (*Z. Naturf.*, vol. 4a, pp. 654–664; December, 1949.)

538.221 **912**

Ferromagnetic Materials and Ferrites: Properties and Applications—M. J. O. Strutt. (*Wireless Eng.*, vol. 27, pp. 277–284; December, 1950.) The parameters controlling the properties of ferrites and other ferromagnetic materials are summarized and the relations between the Q value of a cored inductor, core size, hysteresis distortion, and saturation limitations are discussed for commercially available core materials. The conditions giving optimum performance are indicated and the possibilities of obtaining small, highly efficient transformers for low-power applications by using ferrite cores are stressed. The very low hysteresis and eddy-current losses with these materials, when used correctly, give a better approximation to an ideal transformer for the lower radio-frequency bands than do other core materials.

538.221 **913**

High-Frequency Permeability of Ferromagnetic Materials—R. Millership and F. V. Webster. (*Proc. Phys. Soc.* (London), vol. 63, pp. 783–795; October 1, 1950.) Measurements of the resistive and inductive permeabilities in the range 150 mc to 10 km were made using a coaxial line with the inner conductor made from the material under investigation. At all frequencies the resistive permeability μ_R is greater than the inductive permeability μ_L; the effective permeability is assumed to be complex and is plotted as a function of μ_R and μ_L against frequency.

538.221:538.24 **914**

Thermal Effects due to Magnetization Processes in Weak Fields—L. F. Bates. (*Jour. Phys. Radium*, vol. 10, pp. 353–363; December, 1949.) Paper given at a meeting of the French Physical Society, describing experimental research carried out at the University of Nottingham. Measurements on Ni, Fe, Co, and various alloys are reported, and specially devised apparatus is described. A quantitative interpretation of the results has been put forward tentatively by Stoner and Rhodes. An account is included of experiments undertaken to verify theories of Néel and of Lawton and Stewart on the structure of the elementary domains in monocrystals; equidistances in agreement with a formula given by Néel were found.

538.221:669.74.018 **915**

Ferromagnetic Interactions in Manganese Alloys—L. Castelliz and F. Halla. (*Acta Phys. Austriaca*, vol. 2, pp. 348–355; February, 1949.)

538.652 **916**

Reversal of Sign of Magnetostriction by Expansion—W. Braunewell and E. Vogt. (*Z. Naturf.*, vol. 4a, pp. 491–495; October, 1949.)

546.431.42–31:536.2.022 **917**

Thermal Conductivity of Barium/Strontium Oxide—G. F. Weston. (*Nature* (London), vol. 166, pp. 1111–1112; December 30, 1950.) Earlier experimental values are criticized and details are given of measurements using a method based on Lees' disk. Preliminary results indicate values of $1-5\times10^{-6}$ cal deg^{-1} cm^{-1} sec^{-1} at 1,000°K, increasing slightly with temperature. The results appear independent of the compression of the original carbonate, and of the state of activation of the oxide.

546.431.824:537.228.1 **918**

The Electromechanical Behavior of BaTiO Single-Domain Crystals—M. E. Caspari and W. J. Merz. (*Phys. Rev.*, vol. 80, pp. 1082–1089; December 15, 1950.) The d_{31} piezoelectric coefficient was measured by both a static and a dynamic method and its value compared with that theoretically derived from the permittivity and spontaneous polarization. Measurements were made from room temperature to 140°C (Curie point, 120°C). The static method, contrary to the dynamic method, shows that d_{31} is not zero above the Curie point but that it decreases slowly with increasing temperature. This effect is attributed to the tetragonal structure induced by the external field through the electrostrictive effect. Observations of optical birefringence confirm this hypothesis.

546.842.221:537.58 **919**

Thorium Sulfide as a Thermionic Emitter—T. E. Hanley. (*Jour. Appl. Phys.*, vol. 21, p. 1193; November, 1950.) The emission from ThS is only a quarter of that from ThO_2 at a brightness temperature of about 1,500°C.

548.0:537.228.1 **920**

Growing Piezoelectric Crystals—A. C. Walker. (*Jour. Frank. Inst.*, vol. 250, pp. 481–524; December, 1950.) A summary of work carried out at the Bell Telephone Laboratories on the growing of large single crystals of ADP, EDT and quartz. Basic principles are indicated and apparatus is described. Problems encountered in the pilot-plant stage of the commercial production of ADP and EDT crystals are discussed.

549.514.51:537.228.1.096 **921**

The Variation with Temperature of the Piezoelectric Coefficients of Quartz—A. C. Lynch. (*Proc. Phys. Soc.* (London), vol. 63, pp. 890–892; November 1, 1950.) "The equivalent electrical circuits of three bars in longitudinal vibration were measured at approximately 25, 52.5, and 80°C. In this range of temperature the temperature coefficients of d_{11} and d_{14} are respectively -2_{30} and $+13_{60}$ parts per million/°C., and there is no evidence to support Cady's suggestion that d_{11} passes through a maximum near room temperature.

The measurements suggest a rather high value for d_{11}: $(-2.21\pm0.1)\times10^{-8}$ cm per esu of potential at 25°C."

621.3.013.24 **922**

The Production of Pulsed Magnetic Fields, using Condenser Energy Storage—K. S. W. Champion. (*Proc. Phys. Soc.* (London), vol. 63, pp. 795–806; October 7, 1950.) The pulsed magnetic field obtained by discharging a capacitor through an air-cored coil is investigated theoretically, and expressions and curves are derived which enable the field produced by a specified coil and capacitor combination to be readily calculated. A switch, preferably electronic, connects the coil to the capacitor to initiate the discharge and then disconnects the two exactly at the end of one cycle. Thus all the stored energy is used to produce the field, and most of it is recovered at the end of the pulse. Coil design is considered in detail and a description is given of a practical air-cooled coil producing a field of 22.7 kilogauss with pulse duration 10.7 ms, when used with an 8-μf capacitor fed from a 25-kv source. See also 90 of 1950 (Raoult).

621.3.066.6:621.775.7 **923**

Electrical Contacts and Powder Metallurgy—N'Guyen Thien-Chi. (*Ann. Radioélect.*, vol. 5, pp. 339–353; October, 1950.) Powder metallurgy has particularly valuable possibilities for the production of sintered electrical contacts. Some pseudo alloys specially useful in this field are discussed, e.g., W (or Mo)/Cu (or Ag), Ag/CdO (or Ni, graphite, etc.), and figures for ductility and malleability are reported. Since in a pseudo alloy each constituent retains its individual nature, the resulting range of properties far exceeds that obtainable with classical metallurgical processes. See also 2817 of 1949.

621.314.63 924

Nonuniform Distributions of Impurity Centres in Dry Rectifiers—E. Spenke. (*Z. Naturf.*, vol. 4a, pp. 37–51; April, 1949.) Typical distributions of impurity centers are investigated in a search for effects related to variation of concentration with distance from counter electrode. The current-voltage relation is presented in a convenient approximate form whose evaluation demands only a knowledge of the potential variation through the barrier layer; this variation is determined for any distribution of impurity centers. The relation between the distribution of impurity centers and the dependence of differential resistance on bias voltage is studied for both backward and forward directions.

621.314.632.1.011.5 925

The Dielectric Properties of Copper-Oxide Rectifiers—J. H. Calderwood, R. Cooper and H. K. Heppel. (*Research* (London), vol. 3, pp. 530–531; November, 1950.) Using an impedance-bridge circuit, measurements of barrier-layer capacitance and differential resistance were made at frequencies between 100 cps and 10 kc on a number of Cu_2O rectifiers. Both quantities varied somewhat with frequency. Loss-angle values showed general agreement with the Debye absorption curve. Over the range 0°–40°C, a shift of absorption to lower frequencies with decreasing temperature was observed.

621.314.634 926

A Study of Electrical Forming Phenomena at Selenium Contacts—H. K. Henisch, and J. Ewels. (*Proc. Phys. Soc.* (London), vol. 63, pp. 861–876; November 1, 1950.) An account is given of current-creep experiments at various temperatures on Se specimens of different impurity content. Two opposing creep mechanisms are, in general, active simultaneously. A theory of current creep is outlined.

621.315.612.4:546.815.824 927

X-Ray Study of the Phase Transition in Lead Titanate—G. Shirane, S. Hoshino, and K. Suzuki. (*Phys. Rev.*, vol. 80, pp. 1105–1106; December 15, 1950.) Measurements in the range −170° to +550°C indicate a change from tetragonal to cubic structure at the Curie temperature, about 490°C.

621.315.617.3 928

Insulating Varnishes—H. Quillatre. (*Electrician*, vol. 145, pp. 1249–1253; December 1, 1950.) The physical and chemical properties required in insulating varnishes are enumerated and a survey is made of the various materials that are available, including silicones and high-temperature resins. The uses of varnishes on electrical and radio components and the methods of application are discussed in some detail.

666.1.037.5 929

The Physical Aspect of Glass/Metal Sealing in the Electronic Valve Industry: Part 3—G. Trébuchon and J. Kieffer. (*Ann. Radioélect.*, vol. 5, pp. 407–418; October, 1950.) The influence of shape parameters on strains in seals is studied for two particular glass-metal combinations; the importance is emphasized of relating the strains in industrial-type seals to those in standard test seals. External factors affecting seals include annealing conditions, humidity, electrical effects, and thermal shock. Maximum tolerable strains are determined, taking account of production economics. The results of the investigation are applied as a basis for industrial specifications covering annealing cycles, properties required in new glasses for sealing to metals and inspection of seals. Part 2: 135 of February.

MATHEMATICS

517.4/.5 930

The Use of Symbolic Calculus in Mathematical Research—S. Colombo. (*Ann. Télécommun.*, vol. 5, pp. 347–364; October, 1950.) Theoretical bases of the technique are summarized and its possible applications in establishing relations characteristic of certain transcendental functions are studied, including Hankel's transformation and higher-order circular and hyperbolic functions. Its use in the study of certain mass distributions and in van der Pol's applications to the analytical theory of numbers is described; other examples of its application are indicated. Symbolic calculus is a useful research tool; its rules are straightforward and rigorous and define necessary, if not always sufficient, conditions of validity. Forty-nine references are given.

517.422 931

The Mellin Transform and its Applications—P. A. Barrucand. (*Ann. Télécommun.*, vol. 5, pp. 381–388; November, 1950.) This transformation, though not so well known as that of Laplace, is one of the most important in mathematics. The principal rules of operation are studied and the transformation is applied to various problems, including the formation of Fourier kernels and the analytical extension of Taylor's series. An appendix gives numerous transformation formulas.

517.432.1 932

A Derivation of Heaviside's Operational Calculus Based on the Generalized Functions of Schwartz—J. J. Smith and P. L. Alger. (*Trans. AIEE*, vol. 68, Part II, Discussion, pp. 944–946; 1949.) Full paper. Summary noted in 1182 of 1950.

519.272 933

The Statistics of Correlated Events: Part 1—C. Domb. (*Phil. Mag.*, vol. 41, pp. 969–982; October, 1950.) One effect of the correlation of events is a change in the mean-square deviation of the number of events occurring in an interval of time t. By analogy with the shot effect in the presence of space charge, this is denoted by a factor Γ, for large values of t, and Γ, is evaluated in terms of the interval distributions between events. For finite intervals t a corresponding factor $\gamma^2(t)$ is introduced which usually tends toward 1 as $t \to 0$. A correlation function for events occurring at times separated by an interval τ is defined, and its relation to $\gamma^2(t)$ is discussed. A generalization of Campbell's theorem applying to correlated events is derived and the problem of the random partitioning of correlated events is discussed.

621.385.832:517.51:681.142 934

The Monoformer—Munster. (*See* 1033.)

517.512.4 935

Table of the Bessel Functions $Y_0(z)$ and $Y_1(z)$ for Complex Arguments. [Book Review]—Computation Laboratory, National Bureau of Standards. Publishers: Columbia University Press, New York, N. Y., 1427 pp., $7.50; 1950. (*Jour. Frank. Inst.*, vol. 250, pp. 587–588; December 1950.) The functions are tabulated for complex arguments defined in polar coordinates along each of the rays $\phi = 0°$, $5° \ldots 90°$; ten-place values of the real and imaginary parts are given for values of $|z|$ from 0 to 10 at intervals of 0.01. Various auxiliary tables and an explanatory introduction are included.

681.142 936

Calculating Instruments and Machines. [Book Review]—D. R. Hartree. Publishers: University of Illinois Press, Urbana, Ill., and Cambridge University Press, London, 138 pp., 21s; 1949. (*Nature* (London), vol. 166, p. 1087; December 30, 1950.) "A very welcome addition to the literature of the subject."

681.142 937

High-Speed Computing Devices. [Book Review]—Engineering Research Associates. Publishers: McGraw-Hill Book Co., Inc., New York, N. Y. 451 pp., $6.50; 1950. (*Jour. Frank. Inst.*, vol. 250, p. 583; December, 1950.) The book is in three parts, dealing respectively with basic elements of machine computation, computing systems, and physical components and methods. The first and last parts deal primarily with electronic equipment, while the second part describes machines of all types. An extensive bibliography is integrated into the subject matter. Recommended to designers, users, and students.

MEASUREMENTS AND TEST GEAR

53.087.6:529.78:53.088 938

Rate Drift of Timepieces—(*Tech. Bull. Nat. Bur. Stand.*, vol. 34, pp. 150–151; October, 1950.) Short account of equipment developed by H. A. Bowman. A relay-type servo system keeps the phase of a crystal-controlled frequency standard in step with the frequency of the timepiece or oscillator under test. The magnitude of the phase shift is automatically plotted against time.

621.317.3:621.396.611.3 939

Principles of Measurements on Coupled Circuits—W. F. Dil. (*Philips Res. Rep.*, vol. 5, insertion slip; June, 1950.) Corrections to article abstracted in 393 of March.

621.317.335.2:621.314.63 940

A New Method of Capacity Measurement on Dry Disk Rectifiers—K. Lehovec. (*Jour. Appl. Phys.*, vol. 20, p. 123; January, 1949.) With an ac voltage and a suitable dc bias applied to the rectifier in series with a small resistor, the characteristic is traced on a cro, using the voltage across the rectifier to give the abscissa and that across the resistance to give the ordinate. The characteristic shows a loop from which the capacitance and resistance can be calculated as a function of voltage, assuming that (a) the rectifier is equivalent to a capacitance shunted by a resistance, and (b) both are functions of the instantaneous voltage only.

621.317.335.2:621.314.63 941

An Oscillographic Method for the Investigation of Dry-Rectifier Barrier Layers—A. Hoffmann. (*Z. angew. Phys.*, vol. 2, pp. 353–359; September 15, 1950.) The assumptions and limitations of Lehovec's oscillographic "loop" method of determining barrier-layer capacitance (see 940 above) are examined in detail. The discussion is restricted to disk-type rectifiers. Measurements made by this method are in good agreement with reactance-bridge measurements; the loop method has the advantage in respect of speed and ability to deal with incomplete rectifier disks, but is unsuitable for work at low values of forward current, on account of unavoidable large errors.

621.317.352:621.396.611.4 942

Simple Method for Measurement of Variations of Damping of Centimetre Waves—Philipp. (*See* 841.)

621.317.4:621.318.2 943

Measurements on Ring-Gap Magnets—E. Schäfer. (*Funk u. Ton*, vol. 4, pp. 519–524; October, 1950.) Leakage flux associated with the gap is calculated to a close approximation and a ballistic method of measuring the flux density in the gap is described.

621.317.444† 944

General Theory, and Experimental Confirmation, of the Moving-Coil Fluxmeter—T. J. Higgins and G. Robertson. (*Trans. AIEE*, vol. 68, part II, pp. 897–907; 1949. Discussion, pp. 907–908.) An inclusive mathematical theory of the operation of the unshunted fluxmeter is developed. Experimental results confirm the general theory. Analogous theory and experimental results are also given for the shunted type of meter.

621.317.7:621.316.8:621.396.822 945

The Measurement of Noise in Resistors—F. Oakes. (*Electronic Eng.* (London), vol. 22, pp. 464–469; November, 1950.) The resistor under test is connected to the input terminals of a calibrated audio-frequency high-gain feedback amplifier, whose output circuit includes either a thermocouple and rms meter, a peak voltmeter, a diode detector circuit, or a cro for monitoring or recording purposes. Precautions necessary, the various types of resistor noise, and the measurement of noise in variable resistors, are discussed. A mixer and filters are used with the amplifier to investigate the frequency distribution of noise.

621.317.7:621.392.26† 946
A Measuring Arrangement for Waveguides—A. E. Pannenborg. (*Philips Tech. Rev.*, vol. 12, pp. 15–24; July, 1950.) Description of equipment used in the Philips laboratories for determining reflection coefficients from measurements of voltage SWR in a waveguide. Accessories include a microwave generator, directional couplers, an attenuator, a crystal rectifier, and a wavemeter of the cavity-resonator or transmission-line type.

621.317.725 947
A New Electrostatic Voltmeter—H. Greinacher. (*Bull. schweis. elektrotech. Ver.*, vol. 40, pp. 816–817; October 15, 1949. In German.) If two metal plates are partly immersed close together in a liquid dielectric, the meniscus rises when a potential difference is applied across the plates. Two voltmeters based on the simple relation existing between the rise of level and the applied potential difference are described, one for microscope reading and the other with a projection scale. The effect has been applied previously for the determination of dielectric constant (see *Helv. Phys. Acta*, vol. 21, pp. 261–272; 1948).

621.317.733:535.416 948
Standing Wave Ratio Bridge—R. W. Caywood and R. A. Bradbury. (*FM-TV*, vol. 10, pp. 19, 50; November, 1950.) A description of the Millen radio-frequency bridge, designed primarily for SWR measurements at frequencies between 1.5 mc and 42 mc. Applications to problems of matching transmitters and receivers to transmission lines and antennas are indicated.

621.317.755:621.3.029.5/.6 949
A Cathode-Ray Oscillograph for Periodic Phenomena of High Frequencies—J. M. L. Janssen. (*Philips Res. Rep.*, vol. 5, pp. 205–240; June, 1950.) A system of electronic stroboscopic scanning of the signal is obtained by mixing it with phase-modulated pulses. The design of the pulse generator and the mixer and synchronization circuits is discussed in detail. The technique has been used for the observation of distorted signals with harmonics up to 30 mc, for the measurement of phase and amplitude characteristics up to 70 mc and for the observation of modulated signals with carrier frequencies up to 70 mc and modulation frequencies up to 20 kc.

621.317.763 950
The Michelson Interferometer at Millimetre Wavelengths—W. Culshaw. (*Proc. Phys. Soc.* (London), vol. 63, pp. 939–954; November, 1950.) The design and operation of an instrument working at a wavelength of 12.5 mm is described. The transmitting and receiving apertures are 6-inch square horns, both partially corrected by metal lenses to give an approximation to plane-wave operation. The beam divider consists of two $\lambda/4$ polystyrene plates separated by an adjustable air gap. Wavelength measurements were made with various path lengths; the results are most accurate when working well inside the Fraunhofer diffraction region. The measured wavelength increases as the spacing is reduced.

The frequency of the source is stabilized by a high-Q cavity used as a radio-frequency discriminator. The frequency was measured with a calibrated frequency meter and the resulting velocity of em waves agrees, within the accuracy of the instrument (1 part in 10^4), with the accepted value. The interferometer has also been used to measure the dielectric constant of low-loss materials, and its use as a substandard of length is discussed.

621.396.615.015.7† 951
A Pulse Generator for the Millimicrosecond Range—R. L. Garwin. (*Rev. Sci. Instr.*, vol. 21, pp. 903–904; November, 1950.) Describes a laboratory generator of pulses with rise and decay times $<2\times10^{-10}$ second at a repetition rate of 120 per second. A mechanical switch in the center conductor of a coaxial line is operated by a 60-cps magnetic field in an external coil. Three simultaneous outputs are available, variable in amplitude from 100 μv to 100 v.

OTHER APPLICATIONS OF RADIO AND ELECTRONS

531.787.6:621.38 952
Diaphragm-Type Micromanometer with Electronic Pickup—(*Tech. Bull. Nat. Bur. Stand.*, vol. 34, pp. 137–139; October, 1950.) Movement of the diaphragm in response to pressure variations is measured by a mutual-inductance micrometer [see 690 of March (Gordon and Richmond)].

534.321.9:620.179.16 953
Application of Ultrasonics in the Testing of Materials—L. Bergmann. (*Z. Ver. Dtsch. Ing.*, vol. 92, pp. 711–718; September 1, 1950.) A review is given of the development of ultrasonic testing apparatus in the two main classes operating respectively by transmission and reflection; the advantages and drawbacks of the two systems are compared. The theoretical basis is given briefly, and commercial apparatus is described. An application still in an early stage is the study of the crystalline structure of materials. Twenty-five references are listed.

621.314.653 954
The Ignitron and its Applications—David and Caussin. (*See* 1015.)

621.316.578.1 955
Electronic Sequence Timing for Compression-Molding Presses—J. H. Wyman. (*Elec. Mfg.*, vol. 42, pp. 114–116; November, 1948.) Details of the construction and mode of operation of a 4-stage sequence timer. This controls the setting of two 3-way tubes and two 2-way tubes which directly govern the air supply to the press.

621.316.578.1:621.385.38 956
Timing Machine Operations with Small Thyratrons—S. C. Rockafellow. (*Product Eng.*, vol. 21, pp. 85–90; November, 1950.) Descriptions and diagrams of circuits for introducing time delay into the control systems of automatic and semiautomatic machines such as presses and test gear.

621.316.74:621.385.38 957
Precision Thermostat for High Temperatures—(*Jour. Frank. Inst.*, vol. 250, pp. 443–445; November, 1950.) Short description of a thermostat developed at the National Bureau of Standards by W. R. Eubank. The resistance of the Pt/Rh wire used for the furnace heater winding changes rapidly with temperature above 1,000°C; this winding forms one arm of an ac bridge, the unbalance voltage from which is amplified and applied to the control grid of a thyratron controlling the current supplied to the heater coil. Furnace temperatures in the range 1,000° to 1,550°C are maintained constant within ±0.1°C for several hours, and within ±1.0°C for several days.

621.318.4:621.365.54† 958
Work-Coils for H.F. Heating—R. A. Whiteman. (*Radio & Telev. News, Radio-Electronic Eng.*, vol. 15, pp. 3A–6A, 28A; October, 1950.) Theory and practice are combined to obtain the optimum design of work coils for induction heating.

621.365.54/.55† 959
The Design of H.F. Generators for Industrial Use and the Development of their Application in France—J. Girardeau. (*Onde élect.*, vol. 30, pp. 488–496 and 542–546; November and December, 1950.) *See* 178 of February.

621.365.54† 960
Some Possibilities of H.F. Induction Heating in the Surface Hardening of Motor-Car Parts—J. J. Leven. (*Ann. Radioélect.*, vol. 5, pp. 419–432; October, 1950.) An account is given of high-frequency generating plant and semiautomatic hardening equipment in industrial use. Results obtained with typical parts are reported.

621.384.611.1† 961
Ejection of the Electron Beam from a Betatron—S. L. Fawcett and E. C. Crittenden, Jr. (*Rev Sci. Instr.*, vol. 21, pp. 935–936; November, 1950.) Modification of scheme proposed by Crittenden and Parkins (3438 of 1946).

621.384.611.2† 962
Synchrotron-Oscillation Resonance—N. M. Blachman. (*Rev. Sci. Instr.*, vol. 21, pp. 908–911; November, 1950.)

621.384.62+621.385.029.63/.64 963
The Control of Electron Streams by means of Progressive Waves (Travelling-Wave Tubes)—Döhler. (*See* 1017.)

621.385.83 964
Note on the Focusing of Electron Beams in Certain Magnetic Fields—P. A. Sturrock. (*Proc. Phys. Soc.*, vol. 63, pp. 954–957; November 1, 1950.) "Equations are set out which determine the focusing properties of electron beams in magnetic fields whose scalar potential has a plane of antisymmetry. From these is derived the condition that a proposed ray-axis and associated focusing requirements should be physically realizable. It is also shown that the fringe effect of fields with sharply defined boundaries may be characterized by a pair of focal lengths, for which formulas are given."

621.385.833 965
A Small Electron Microscope—J. H. Reisner and E. G. Dornfeld. (*Jour. Appl. Phys.*, vol. 21, pp. 1131–1139; November, 1950.) The instrument has a resolution of 100 A. The magnetic lenses are energized by permanent magnets, the accelerating voltage is 50 kv, variable by 500 v for focusing. Plates and specimens can be rapidly changed. Direct magnifications of 1,500, 3,000, and 6,000 are available.

621.385.833 966
Electron Scattering and Image Formation in the Electron Microscope—B. v. Borries. (*Z. Naturf.*, vol. 4a, pp. 51–70; April, 1949.)

621.387.4† 967
Statistical Limitations on the Resolving Time of a Scintillation Counter—R. F. Post and L. I. Schiff. (*Phys. Rev.*, vol. 80, p. 1113; December 15, 1950.) Discussion of the limitations on resolving time that arise from fluctuations in the emission, transmission, and collection of scintillation photons.

621.387.4† 968
A Study of the Deterioration of Methane-Filled Geiger-Müller Counters with External Cathode—D. Blanc. (*Jour. Phys. Radium*, vol. 10, pp. 411–414; December, 1949.) A useful life ranging from 6×10^7 to 2×10^8 impulses is observed. The limitation of life is due to deposition of material on the cylinder, with consequent reduction of its work function.

621.387.4†:621.383 969

Multiplier Phototubes in Scintillation Counters—Hickman. (*See* 1016.)

621.395.625.3.029.42:611.81 970

Magnetic-Tape Recorder for Very-Low-Frequency Phenomena—P. E. Green, Jr. (*Rev. Sci. Instr.*, vol. 21, pp. 893–895; November, 1950.) Equipment for recording electrical 1 to 100-cps signals for subsequent reproduction. The signals are used to modulate the frequency of a 1-kc carrier wave. The tape speed for reproduction is 5 times the recording speed, so that the output from the demodulator gives the original signals with frequencies multiplied by 5.

PROPAGATION OF WAVES

538.566.2 971

Research on the Propagation of Sinusoidal Electromagnetic Waves in Stratified Media: Application to Thin Layers: Part 1—Abelès. (*See* 857.)

621.396.11 972

Group and Phase Velocities from the Magneto-ionic Theory—H. A. Whale and J. P. Stanley. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 82–94; 1950.) "When a radio wave is transmitted through a medium consisting of free electrons it is well known that the product of the refractive index μ and the 'group refractive index' μ' is equal to unity. When a steady magnetic field is imposed on the medium, μ becomes a complicated function of wave frequency and the direction of propagation, μ' is even more complicated and the product $\mu\mu'$ is no longer equal to unity. It is shown that it is then convenient to consider values of the product $\mu\mu'$ for different frequencies and directions of propagation, and sets of curves are given from which the behavior of this product can be visualized as both wave frequency and direction of propagation are varied. The curves were computed by the use of the EDSAC electronic computer. The use of the curves and the conditions under which they may be applied are discussed briefly."

621.396.11:532.517.4:551.510.5 973

Scattering of Electromagnetic Waves by Atmospheric Turbulence—E. C. S. Megaw. (*Nature* (London), vol. 166, pp. 1100–1104; December, 1950.) Information concerning the large-eddy end of the spectrum of turbulence in the free atmosphere, obtained from analysis of records of angular fluctuations of star images, and concerning the small-eddy end of the spectrum, derived from observations of stellar brightness fluctuations, is discussed. Consistency of the values of total fluctuation of refractive index derived from these two sources indicates that it is correct to assume that "all the observations can be accounted for by an average spectrum of turbulence which is a permanent characteristic of the atmosphere, and that this is, in fact, the Kolmogoroff spectrum."

Formulas resulting from a theory of scattering of short radio waves are quoted and differences between results deduced from this theory and from that of Booker and Gordon (1757 of 1950) are discussed. Theoretical results are compared with observations of field strengths of 10-cm waves on oversea and overland paths; these apparently confirm that "turbulent scattering, at least of centimeter waves, represents a permanent, if slightly variable, modification of normal propagation beyond the horizon."

621.396.11:535.34:551.510.535 974

The Absorption of Long and Very Long Waves in the Ionosphere—J. P. Stanley. (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 65–72; 1950.) "Experimental observations on a series of low frequencies have been used to show that models of the ionosphere in which the ionization density increases linearly or parabolically with height are unsuitable for explaining long and very-long-wave reflection phenomena. Agreement with observation can however be obtained if an absorbing or *D* region of small ionization density but several kilometers in thickness is assumed to lie below the main reflecting region. A model in which the ionization density increases exponentially with height is found to include such an absorbing region; this model is used to deduce values for the ionization gradient and the electronic collision frequency in the very-long-wave reflecting region."

621.396.11:535.34:551.510.535 975

Attenuation of the Extraordinary Component in the Ionosphere E_1 Layer—Becker. (*See* 887.)

621.396.11:551.510.535 976

Notes on the Ionosphere Reflection Coefficient—Scattering of Ground Wave and its Conversion into Space Wave—C. Glinz. (*Tech. Mitt. schweiz. Telegr.-Teleph Verw.*, vol. 28, pp. 224–228; June 1, 1950. In French.) French version of paper noted in 1221 of 1950.

621.396.11:621.396.812.4 977

Comparison of Tropospheric Reception at 44.1 Mc/s and at 92.1 Mc/s over the 167-Mile Path, Alpine, New Jersey, to Needham, Massachusetts, 1947–1948—G. W. Pickard and H. T. Stetson (*Jour. Atmos. Terr. Phys.*, vol. 1, pp. 32–36; 1950.) Extended version of paper presented at the International Council of Scientific Unions, Oslo, August, 1948. Daily measurements of field intensity are analyzed. The two transmitting antennas are on the same tower and radiate approximately equal power on the horizon. The records for the two transmissions show similar daily and monthly variations, both of which can be correlated with atmospheric refraction as determined by calculation from surface meteorological data at Boston. This correlation suggests a common mode of propagation for the two transmissions, the results indicating that the main mode is by refraction in the lower atmosphere rather than by reflection or by ducts.

621.396.11.029.5 978

A Study of Inospheric Ray Field Intensity in the 10–30 and 500–1100 kc/s Bands—K. W. Tremellen. (*Marconi Rev.*, vol. 13, pp. 153–167; 4th Quarter, 1950.) A re-examination of data recorded in 1922–23 and 1933–34 in the light of present-day knowledge of the ionosphere. The data have been analyzed in relation to season, time of day, latitude, sunspot and magnetic activity, direction of propagation, and polarization. Differences in field strength were noted for oversea and overland paths, and signals at low frequencies were often received from distant stations by both round-the-world paths. Consistent results were obtained over daylight paths, but the propagation phenomena over paths partly or wholly in darkness were variable and have not been satisfactorily explained.

621.396.11.029.63(494) 979

Observations on the Propagation of Decimetre Waves in Switzerland—J. Dufour. (*Tech. Mitt. schweiz. Telegr.-Teleph. Verw.*, vol. 28, pp. 417–422; November 1, 1950. In French.) Paper presented at the URSI congress at Zürich, September, 1950. Field-strength measurements were made over a period of nearly two years on a wavelength of 96 cm, using a 30-w transmitter at Chasseral in the Jura, 1610 m above sea level, and receivers at Geneva, Uetliberg, Gurten and the Jungfraujoch. The profiles of these paths are illustrated; all afford uninterrupted "vision." Correlation of observations at the different receivers is found only for large-scale variations. Maximum, minimum and mean values were noted for 2-hour periods; the results were analyzed statistically, and are shown diagrammatically and discussed in relation to seasonal, time-of-day and atmospheric-refraction effects. The unexpected unreliability of the Jungfraujoch path seems to indicate that for steady reception the path should include features capable of eliminating multipath effects due to ground reflections.

621.396.812.2:551.510.535 980

A Study of the Horizontal Irregularities of the Ionosphere—B. H. Briggs and G. J. Phillips. (*Proc. Phys. Soc.* (London), vol. 63, pp. 907–923; November 1, 1950.) The theory of diffraction by a random screen developed by Booker, Ratcliffe and Shinn (428 of March) is presented in a convenient form for practical application in ionospheric experiments. It is shown that measurements of the correlation of the fading of the reflected wave observed at spaced receiving points can be used to find the extent of the angular spreading of the downcoming wave. Histograms are given to show the frequency of occurrence of different degrees of angular spreading observed during a series of experiments using pulse transmissions at vertical incidence. For a frequency of 2.4 mc it is most common to find that the downcoming wave has an angular spread such that the amplitude falls to half value at an angle of 5° for regions *E* and *F*. For a frequency of 4.8 mc, the corresponding value for region *F* is 2.5°. There is no evidence for any pronounced seasonal or diurnal variations.

621.396.812.3:551.510.535 981

Periodic Fading of Short-Wave Radio Signals—S. R. Khastgir and P. M. Das. (*Proc. Phys. Soc.* (London), vol. 63, pp. 924–930; November 1, 1950.) Periodic fading of cw signals of frequency 4.84 mc over a distance of 240 km was observed in India during the evening and early night hours of December, 1948, and January, 1949. The two main types of periodic fading were (a) sinuous fading at 25 to 60 cycles per minute, attributed to interference between the lower- and upper-trajectory extraordinary waves reflected from the *E* region, and (b) periodic fading at 2 to 10 cycles per minute, attributed to interference between the two waves singly and doubly reflected from the F_2 region or singly reflected from regions *E* and F_2. This could be accounted for by a vertical drift of the ionospheric layer or layers, at a rate agreeing with observed values. These two types of fading were sometimes superimposed. In a few patterns there was evidence of frequencies of 4 to 12 cps, the origin of which is unknown.

RECEPTION

621.396.621 982

An Up-to-Date, High-Fidelity Receiver using Modern Valves: Part 2—The High-Frequency Circuits, Power Supply, and Complete Arrangement—J. Rousseau. (*TSF pour Tous*, vol. 26, pp. 409–416; December, 1950.) One stage of high-frequency amplification is provided, using a 6BA6 miniature pentode. In the frequency changer a conversion slope of 1.1 ma per v is obtained using a 6BA6 tube as mixer with a 6J5 tube as oscillator. The wave-selection arrangements provide two short-wave and two medium-wave bands, and one long-wave band. Two 6BA6 tubes in push-pull give high gain combined with stability in the intermediate-frequency stage, and the three-winding intermediate-frequency transformer has a response curve approaching the ideal square-top form. The detector uses a 6H6 double diode. Automatic gain control without amplification is provided by means of a three-diode circuit, double diodes being used to suit the balanced system. The visual tuning indicator is a 6AF tube. The power unit uses two GZ40 full-wave rectifiers in parallel, delivering 170 ma. Circuit diagrams with all component details are given. Part 1: 440 of March.

621.396.621.004.67 983

Most-Often-Needed 1950 Radio Diagrams and Servicing Information. [Book Review]—M. N. Beitman. Publishers: Supreme Publications, Chicago, Ill., 192 pp., $2.50. (*Radio & Telev. News*, vol. 44, pp. 126–127; October, 1950.) The tenth volume of this popular servicing series. Includes diagrams and data for sets made by nearly 30 manufacturers. The previous volume was noted in 2317 of 1949.

STATIONS AND COMMUNICATION SYSTEMS

621.39.001.11 984

Information Theory—W. Jackson. (*Nature* (London), vol. 167, pp. 20–22; January 6, 1951.) An account of the proceedings at a symposium in the rooms of the Royal Society, September, 1950, with short summaries of the various papers presented. Applications for copies of the proceedings should be sent to the Electrical Engineering Department, Imperial College of Science and Technology, London, S.W. 7, and will be met as equitably as possible from the limited number available.

621.39.09 985

Frequency Compression—P. Marcou. (*Ann. Télécommun.*, vol. 5, No. 10, pp. 321–337; October, 1950.) Paper presented at the conference at the Sorbonne, April–May, 1950, on Signal and Information Theory. Simple compression of a frequency spectrum involves an increase in transmission time. To avoid this the signal must be suitably "cut" before compression. A theoretical analysis of this principle is given. The conditions which must be satisfied for intelligibility not to be lost and the effect of compression on different instantaneous frequency components of the signal are investigated. Theoretically, compression by frequency division, with subsequent multiplication on reception, is a satisfactory solution of the problem of narrow-band transmission. See also 3155 of 1950 (Loeb).

621.396.82:621.396.41 986

Interference on Multi-Channel Circuits—L. Lewin. (*Wireless Eng.*, vol. 27, pp. 294–304; December, 1950.) A detailed mathematical analysis of the interference in multichannel systems due to nonlinear relations between the input and output signals. Assuming an output-input relation which is a power series of the input signal, suitably delayed, the harmonic content of the output corresponding to a single pure-tone signal is found and compared with the interchannel interference when many channels are operative. In general, groups of interference products which are not random in phase are produced and a complex analysis is necessary to deduce the resultant interference from the intensities of the various harmonics. The standard method of measurement is justified only when the higher harmonics are negligible compared with the second and third orders. Distortion due to mismatches on a long feeder line is examined in detail; under such conditions the total interference may be appreciable when the absolute values of the lower harmonics are only small.

621.396.931/.932 987

Planning V.H.F. Mobile Systems—E. G. Hamer: E. R. Burroughes. (*Electronic Eng.*, vol. 22, p. 483; November, 1950.) Comment on 2629 of 1950 and author's reply.

621.396.931 988

Multiplex Design—F. B. Gunter. (*FM-TV*, vol. 10, pp. 16–18; November, 1950.) The Westinghouse Type-FB FM multiplex transmitter-receiver for operation in the 960-mc band is described, photographs and sectional and circuit diagrams being included. Both sender and receiver are crystal-controlled. Up to 7 speech channels are available, with a radio-frequency output power into the antenna of 5 w and an over-all distortion <1 per cent.

621.396.931 989

Design of Mobile Radio Communication Equipment for Land Mobile Services operating on Frequencies between 152–174 Megacycles—R. A. Beers, W. A. Harris, and A. D. Zappacosta. (*Trans. AIEE*, vol. 68, part II, pp. 1232–1239; 1949.) The rapid increase of the number of systems using the frequency band 152 to 174 mc, and the problems resulting from this increase, are discussed briefly. Equipment is described that has been designed to double the number of channels that can be used in any one locality.

621.396.931:624.193 990

Transmission Through Tunnels—J. B. Lovell Foot. (*Wireless World*, vol. 56, pp. 456–458; November and December, 1950.) Report of tests by the GEC Research Laboratories in railway tunnels, with the object of communication between signal boxes and moving trains. Frequencies of 82, 460, and 1,400 mc were used. At the lower frequencies the tunnel attenuation is high, while the higher frequencies offer a practical solution of the problem, though the use of frequencies above about 500 mc would probably introduce equipment problems and increase the cost.

621.396.619.13 991

Frequency Modulation. [Book Review]—K. R. Sturley. Publishers: Chemical Publishing Co., Brooklyn, N. Y., 94 pp., $4.75. (*Radio and Telev. News*, vol. 44, p. 126; October, 1950.) Designed for the radio technician, this book, although small, "manages to convey an amazing amount of information on the subject." The treatment is largely mathematical.

SUBSIDIARY APPARATUS

621–526 992

An Analysis of Relay Servomechanisms—D. A. Kahn. (*Trans. AIEE*, vol. 68, part II, pp. 1079–1087; 1949. Discussion, pp. 1087–1088.) Full paper. Summary abstracted in 1252 of 1950.

621–526 993

Carrier Compensation for Servomechanisms—H. E. Blanton. (*Jour. Frank. Inst.*, vol. 250, pp. 391–407 and 525–542; November and December, 1950.) The problems involved in the provision of compensation to improve the stability and performance of systems using carrier-frequency techniques for data transmission are described. The theoretical forms of the compensation transfer characteristic for both amplitude and phase response with frequency are deduced and compared with the characteristics normally obtained from realizable circuits. The accuracy of the latter is limited by component tolerances and dependence on the stability of the carrier frequency. The various types of passive electrical network for obtaining desired carrier-compensation transfer characteristics are discussed. The main disadvantage of passive *RLC* networks is the nonlinearity introduced by the actual inductances used; such networks have, however, many distinct advantages.

621.314.6 994

Representation and Generalized Basis of Calculation for Rectifiers with Buffer Capacitors—H. Verse. (*Bull. schweiz. elektrotech. Ver.*, vol. 40, pp. 818–826; October 15, 1949. In German.) Rectifiers of this type are used commonly for supplying anode voltage in communications, high-frequency and measurement apparatus, and the like. The circuits are compared with those using inductance coils; the basic half-wave rectifier is discussed in detail, and more complex arrangements are examined by means of equivalent circuits. A simple general method of calculation based on graphical data is developed, and a numerical example is worked out.

621.314.63:621.317.335.2 995

An Oscillographic Method for the Investigation of Dry-Rectifier Barrier Layers—Hoffmann. (*See* 941.)

621.314.63:621.317.335.2 996

A New Method of Capacity Measurement on Dry Disk Rectifiers—Lehovec. (*See* 940.)

621.314.632.1† 997

Conductivity Contour of the Barrier Layer in the Copper-Oxide Rectifier, as obtained from H.F. Measurements, and its Ordering into Space-Charge Zones—G. Pfotzer. (*Z. Naturf.*, vol. 4a, pp. 691–706; December, 1949.)

621.316.93 998

Performance Characteristics of Lightning Protective Devices—(*Trans. AIEE*, vol. 68, part II, pp. 1333–1336; 1949. Discussion, p. 1336.) Combines in one report the data on lightning arresters of various types published previously by the AIEE Lightning Protective Devices Subcommittee in a number of separate reports, with such modifications as are required to bring the material up to date. In addition, data covering line expulsion-type arresters, and data on rod-gap spark-over voltages are included for co-ordination with lightning-arrester characteristics.

621.319.332 999

New 200000-V Electrostatic Generators—P. Hémardinquer. (*Elektron, Linz*, pp. 360–361, 386; 1950.) A brief account, taken from *Électricité*, October, 1950, of an influence machine developed at the Laboratoire National de la Recherche Scientifique and commercially available. A rotor with metal segments of thickness 2 to 6 mm revolves inside a sealed container under a pressure of 25 to 30 atm, this increased pressure multiplying the power 200-fold. Currents up to 10 ma can be supplied, and power output, not voltage, is proportional to size. The rotor can be driven by any convenient means. The machine is robust and cheap, and is suitable for operating electron microscopes and television apparatus as well as for agricultural and medical applications.

621.319.339:621.316.722 1000

Voltage Regulation for Van de Graaff Electrostatic Generators—J. Taieb. (*Onde élect.*, vol. 30, pp. 462–468; November, 1950.) Discussion of different methods in use for stabilizing potentials of several million volts, and description of the system proposed for the 5-mv generator under construction for the French Atomic Energy Commission.

621.396.682:621.316.935.1 1001

Voltage Doubler with Saturable Reactor—R. Aschen. (*Radio franc.*, pp. 5–8; October, 1950.) In the arrangement described the basic voltage doubler is modified by inclusion of (a) a stabilizing saturable reactor whose impedance decreases as the current through it increases, (b) a circuit to protect the electrolytic capacitors from application of reverse voltage in case of failure of one of the rectifier diodes, and (c) a diode circuit for stabilizing the dc output. Some design details are given.

TELEVISION AND PHOTOTELEGRAPHY

621.385.832:535.37 1002

Color Cathode-Ray Tube with Three Phosphor Bands—C. S. Szegho. (*Jour. Soc. Mot. Pic. Telev. Eng.*, vol. 55, pp. 367–376; October, 1950.) The screen of a cathode-ray tube for projection color television has three phosphor bands fluorescing respectively in red, blue, and green. The tube is suitable for use with field- or line-sequential transmissions; in the former case the bands are arranged one below the other, in the latter case side by side. The resulting three images are superimposed by the optical projection system. There are two inherent drawbacks: the screen area is inefficiently used from the standpoint of light output, and the resolution is inadequate.

621.397.5:535.623 1003

Color Television—F. H. McIntosh and A. F. Inglis. (*Jour. Soc. Mot. Pic. Telev. Eng.*, vol. 55, pp. 343–366; October, 1950.) The field-sequential (CBS), line-sequential (CTI), and dot-sequential (RCA) systems are compared from the point of view of service to the public. An addendum deals briefly with the frequency-interlace system (GEC) and the "Uniplex" system (CTI). See also 249 of February.

621.397.5:535.623 1004

Colour Television: Frequency—Interlace System—A. Dinsdale. (*Wireless World*, vol. 56, pp. 443–449; December, 1950.) A description of the system proposed by Dome (466 of March), based on data supplied to the FCC by the General Electric Company.

621.397.5:621.315.212 1005

Television Terminals for Coaxial Systems—L. W. Morrison, Jr. (*Trans. AIEE*, vol. 68, part II, pp. 1193–1199; 1949.) Full paper. Summary abstracted in 1267 of 1950.

621.397.5:778.5 1006

Video Recordings Improved by the Use of Continuously Moving Film—W. D. Kemp. (*Tele-Tech*, vol. 9, pp. 32–35, 63; November, 1950.) Detailed description of BBC technique. The film moves continuously, but optical compensation methods are used to obtain a succession of separate pictures as with ordinary cinema film. Details of these methods are given. The system is normally used to record at 25 frames per second from a television picture with a repetition rate of 25 per second, but a simple modification permits recording at 24 frames per second from a picture with repetition rate 30 per second. Application of a 10- to 15-mc sine-wave deflection voltage to the scanning beam reduces line structure in the record.

621.397.5:778.5 1007

Comparative Study of the Techniques for Recording and Reproducing Moving Images by Cinematography and by Television—M. J. de Cadenet. (*Ann. Télécommun.*, vol. 5, pp. 389–404 and 406–416; November and December, 1950.)

621.397.5(083.74) 1008

Australian Television Standards—*Proc. IRE* (Australia) vol. 11, pp. 289–291; November, 1950.) Details of the standards determined by the Australian Broadcasting Control Board are given.

621.397.743:621.392.5:621.315.212 1009

Equalization of Coaxial Lines—Gould. (*See* 836.)

621.397.8 1010

The Range of the 819-line Television Transmitter at Lille—(*Radio prof.* (Paris), vol. 19, p. 15; October, 1950.) Rough chart of the service area. Peak power for vision is 200 w; carrier power for the sound channel 35 w. Vision signals are received 94 km (58 miles) to the E.N.E., in which direction the antenna has a power gain of about 10.

621.397.5 1011

Practical Television Engineering. [Book Review]—S. Helt. Publishers: Murray Hill Books, New York, N. Y., 694 pp., $7.50. (*Radio & Telev. News*, vol. 44, p. 124; October, 1950.) A comprehensive treatment designed for manufacturing, sales and broadcasting engineers, students, and technicians.

TRANSMISSION

621.396.619:621.392.26†
:621.396.615.141.2 1012

The Development of Modulation on Waveguides—J. Ortusi and P. Fechner. (*Ann. Radioélec.* vol. 5, pp. 331–338; October, 1950.) Modulation of the energy fed along a waveguide by means of a magnetron coupled to it by a coaxial line was described in 54 of 1948 (Gutton and Ortusi). The design of the magnetron is discussed in relation to modulation factor and bandwidth; a magnetron with grooves linking the cavities is described. Static and dynamic impedance and conditions for minimizing losses are considered. The influence on the interelectrode high-frequency field of various parameters is investigated, and space-charge resonance is studied as a function of dc magnetic field and anode potential. Application to a television transmitter operating on a carrier wavelength of 23 cm with modulation frequencies up to 30 mc is described.

TUBES AND THERMIONICS

537.525.92:537.533:621.385.832 1013

Space-Charge Effects in Electron Beams and their Reduction by Positive-Ion Trapping—E. G. Linder and K. G. Hernqvist. (*Jour. Appl. Phys.*, vol. 21, pp. 1088–1097; November, 1950.) "An equilibrium condition may be established in which the electron and ion densities are equal, and then space-charge forces will be neutralized. Under these conditions high current densities may be produced at low voltages. A theory of ion trapping is discussed, and the equilibrium condition is formulated. Experimental data are presented which were obtained by the application of microsecond pulses to the beam. This technique is described, and its advantages and possibilities are mentioned. Data are given on beam spread as a function of current, voltage, and pressure. Data on the improvement due to ion trapping are included. An increase of current density by a factor of 30 was observed with the structures tested. Results are included on ion build-up time as a function of pressure, and on beam noise and stability in the presence of trapped ions."

537.533.8:621.396.615.14 1014

On the Time Delay of Secondary Emission—G. Diemer and J. L. H. Jonker. (*Philips Res. Rep.*, vol. 5, pp. 161–172; June, 1950.) The upper frequency limit of a disk-seal dynatron is found to be 2.4 kmc; from this an upper limit of 3×10^{-11} second is deduced for the time lag τ of secondary-electron emission. Measurements of the admittance of an uhf dynatron at 300 mc indicate that τ is $<10^{-11}$ second; an upper limit of the order of 10^{-14} to 10^{-15} second can be estimated theoretically from transit-time effects within the secondary-emission material.

621.314.653 1015

The Ignitron and its Applications—R. David and C. Caussin. (*Onde élect.*, vol. 30, pp. 476–484; November, 1950.) Both sealed and vacuum-maintained types are discussed and practical applications as rectifier elements and as inertialess contactors are described.

621.383:621.387.4† 1016

Multiplier Phototubes in Scintillation Counters—R. E. B. Hickman. (*Electronic Eng.* (London), vol. 22, pp. 474–476; November, 1950.) The advantages and the principles of operation of scintillation counters using multiplier photocells are discussed and the principal characteristics of Types 931A, IP21, IP22, IP28, and 5819 photocells are tabulated.

621.385.029.63/.64+621.384.62 1017

The Control of Electron Streams by means of Progressive Waves (Travelling-Wave Tubes)—O. Döhler. (*Funk u. Ton*, vol. 4, pp. 493–507; October, 1950.) Description of the principle of the traveling-wave oscillograph and accelerator and theoretical analysis of the operation of the Kompfner-Pierce type of traveling-wave tube.

621.385.029.63/.64 1018

H.F. Amplification by Interaction of Two Electron Beams—J. Labus. (*Arch. elekt. Übertragung*, vol. 4, pp. 353–360; September, 1950.) A physical explanation is developed of the operation of parallel-beam tubes. The theory leads to a boundary-value problem whose solution yields four eigenvalues, indicating a coupling action between the two beams via their common em field. To confirm this, an arrangement is investigated in which the two beams are separated coaxial hollow cylinders; amplification increases with tightness of coupling. Because of the elastic properties of the electron charges within the stream, two waves with different phase velocities are propagated.

621.385.029.63/.64 1019

The Active Coaxial Tube—P. A. Clavier. (*Phys. Rev.*, vol. 77, p. 302; January 15, 1950.) The possibility indicated by Roberts (608 of 1950) of obtaining gain in a traveling-wave tube in the direction opposite to that of the electron beam is confirmed. Considering a waveguide traversed by a beam, the gain parameters have been derived as functions of the Larmor frequency, the electron plasma frequency, the wavelength, and the guide diameter. The importance of proper matching is emphasized.

621.385.029.63/.64 1020

On the Properties of Valves using a Constant Magnetic Field: Traveling-Wave Valves with Magnetic Field: Part 4—O. Doehler, J. Brossart and G. Mourier. (*Ann. Radioélect.*, vol. 5, pp. 293–307; October, 1950.) Linear theory given in part 3 [1544 of 1949 (Brossart and Doehler)] is developed further, and a more exact calculation is made of the small-signal gain. Two further wave modes are found; these undergo neither amplification nor attenuation. The major cause of nonlinear effects is anode absorption. Efficiency is higher for beam injection potentials small compared with anode potential; a simple expression is given for the efficiency in that case.

621.385.029.63/.64:537.533.7 1021

Dynamic Electron Flow under the Influence of Dynamic Fields—König. (*See* 854.)

621.385.029.63/.64:621.396.615.141.2 1022

Space-Charge Effects in Magnetic-Field Traveling-Wave Valves—R. Warnecke, O. Doehler, and D. Bobot. (*Ann. Radioélect.*, vol. 5, pp. 279–292; October, 1950.) Development of discussion on the type of tube previously described [2064 of 1950 (Warnecke et al)], where space-charge effects were assumed negligible. Actual measurements, e.g., of anode current as a function of magnetic field, do not agree with results to be expected from classical theory; the discrepancies are ascribed to interaction between electrons moving with different velocities [see 333 of 1950 (Warnecke, et al)], which gives rise to amplification of oscillations. This effect is investigated analytically and confirmed for a tube with slotted delay line [1584 of 1949 (Brillouin)]. The effect of space charge itself is negligible.

621.385.15 1023

Statistical Theory of Electron Multipliers—F. Sauter. (*Z. Naturf.*, vol. 4a, pp. 682–691; December, 1949.)

621.385.032.213.1.017.72 1024

End-Cooling of Power-Tube Filaments—J. W. Clark and R. E. Neuber. (*Jour. Appl. Phys.*, vol. 21, pp. 1084–1087; November, 1950.) "The differential equation defining the relation between temperature and distance in that portion of a vacuum tube filament which is cooled by both conduction and radiation is formulated. This equation has been solved by numerical integration; the results are presented as a set of universal curves in a form convenient for use in vacuum tube design. The calculations agree well with some experimental measurements which were made to verify the theory."

621.385.032.216 1025

Effect of Coating Composition of Oxide-Coated Cathodes on Electron Emission—E. G. Widell and R. A. Hellar. (*Jour. Appl. Phys.*, vol. 21, pp. 1115–1118; November, 1950.) Experiments indicate that maximum electron emission under saturation conditions is obtained from a solid solution containing SrO and BaO in a molecular ration of about 7 to 3. Maximum size of the co-precipitated carbonate particles is obtained with the same ratio of constituents. Tubes with such cathode coatings showed no measurable electron-emission decay for a pulse duration of 10 μs.

621.385.032.216 1026

The Spectral Emittance of Nickel and Oxide-Coated-Nickel Cathodes—S. L. Martin and G. F. Weston. (*Brit. Jour. Appl. Phys.*, vol. 1, pp. 318–324; December, 1950.) Knowledge of the emittance is required to derive the cathode temperature from the observed brightness. Values at a wavelength of 0.66 μ have been measured for various oxide-coated cathodes and for nickel cores. The effects of stoving or baking treatment, temperature, getter flash, and (in oxide-coated cathodes) surface texture are discussed.

621.385.032.216:535.215 1027

Photoelectric Effect in Oxide Cathodes—J. Debiesse and R. Champeix. (*Le Vide*, vol. 4, pp. 545–552; January, 1949). A recapitulation is given of results of experiments reported previously (607 and 1817 of 1948). Treatment of oxide cathodes encouraging thermionic emission reduces their photoelectric sensitivity. Simple calculations of the numbers of photons, electrons, Ba atoms, and oxide molecules involved in the mechanism tend to show that the phenomena observed are due to a combination of photoelectric effect and variation of conductivity of the oxide layer. The loss of photosensitivity following thermal activation is attributed to an excess of Ba atoms at the surface, as previously suggested by de Boer.

621.385.032.216.2 1028

Base-Metal Effects in Thoria-Coated Filaments—H. Nelson. (*Jour. Appl. Phys.*, vol. 21, pp. 1194–1195; November, 1950.) Adherence of thoria to the metal filament is good for Pt but poor for W, as expected from the relative coefficients of thermal expansion. It is to be expected that a stoichiometric excess of metal in the crystal lattice of the thoria is associated with a low work function; experiment provided confirmation of this, higher thermionic activity being observed for a Ta base than a Pt base, since Ta is a better reducing agent.

621.385.032.3 1029

The Length of Life of an Incandescent Tungsten Spiral and the Rate of Evaporation of Tungsten in High Vacuum—E. Baş-Taymaz. (*Z. angew. Phys.*, vol. 2, pp. 374–376; September 15, 1950.)

621.385.5:621.318.572 1030

A 30-Element Electrostatically-Focused Radial Beam Tube—A. M. Skellett and P. W. Charton. (*Tele-Tech*, vol. 9, pp. 26–27, 59; November, 1950.) Description of a tube for high-speed sequential switching, using beam deflection. Two types are available, one having all the grids except one connected together and separate anode leads, the other having all the anodes except one strapped and separate grid leads. Each of the 30 sections has a transconductance of 12 μmhos, a 5-mΩ anode load, and an amplification factor of 60. Normal operating conditions are: anode voltage 450 v, beam current 60 μa, cathode bias 76 v, and a 6-phase deflection voltage of 300 v rms. Cross-talk does not exceed −30 db and sweep speeds up to 10^6 per second are possible.

621.385.832 1031

Fundamentals and Applications of Colour-Trace Tubes [Farbschriftröhren]—P. G. Violet. (*Funk u. Ton*, vol. 4, pp. 530–543; October, 1950.) German war-time development of a type of dark-trace tube is described. The screen has a coating of microcrystalline KCl, which develops red to dark-blue coloration according to the intensity of the incident radiation. The coloration disappears on warming, which is effected by electrical heating of an adjacent, very thin, transparent layer of tungsten. Other methods of obliterating the trace are "wiping" the screen at much greater intensity or applying an electric field. Using a 4-mm trace with resolution 1:150, trace velocities of 100 ms are attainable. Applications of these tubes in communication, measurement, facsimile, and color-television systems are described and discussed.

621.385.832 1032

An 'Ideal' Post Deflexion Accelerator C.R.T.—L. S. Allard. (*Electronic Eng.* (London), vol. 22, pp. 461–463; November, 1950.) The final accelerating field is introduced between two parallel sheets of wire gauze placed very near and parallel to the fluorescent screen. In this way the deflector-plate sensitivity is unaffected and scan distortion is completely eliminated, but owing to the emission of secondary electrons the resolution and contrast range are reduced. The author considers that the disadvantages of the tube outweigh its advantages for commercial use. See also 2397 of 1949 (White).

621.385.832:517.51:681.142 1033

The Monoformer—A. C. Munster. (*Radio & Telev. News, Radio-Electronic Eng.*, vol. 15, pp. 8A–9A; October, 1950.) Description of a device which may be used to provide a signal corresponding to any single-valued function to an accuracy within 1 per cent. A small electrostatic cathode-ray tube is used in which the phosphor screen is replaced by an Al target disc on which the desired function is represented by the boundary of a carbon-ink coating. A simple feedback loop connects the target and the *y* deflection plates. When independent signals are applied to the *x* plates the electron beam traces the boundary line and an output representing the desired function is obtained at the *y* plates. Applications in analog computers, volume compressors, and expanders, and waveform generators, are mentioned. See also 1355 (No. 88) and 2814 of 1950 (Schultz, Calvert, & Buell).

621.385.832:681.142 1034

Electrostatic Storage Tube—S. H. Dodd, H. Klemperer, and P. Youtz. (*Elec. Eng.*, vol. 69, pp. 990–995; November, 1950.) "A beam-deflection electrostatic tube has been developed to store binary-coded information at two stable potential levels, 100 v apart, for digital computers or communications systems. A single 2,000-v electron beam writes or reads one of 400 binary digits on a 4-inch target. A 100-v electron flood replaces leakage and retains stored information indefinitely. The potential boundary stability on the storage surface is assured by a mosaic of conducting beryllium squares."

621.396.615.141.2:621.396.619:621.392.26† 1035

The Development of Modulation on Waveguides—Ortusi and Fechner. (*See* 1012.)

621.396.615.142 1036

The Generation of Electromagnetic Oscillations in V.M. Valves with High Efficiency—R. Gebauer. (*Z. angew. Phys.*, vol. 2, pp. 415–422; October, 1950.) Tubes of the type having two oppositely phased high-frequency gaps are considered, and the relation between drift-path length, high-frequency modulation depth, and over-all efficiency is studied both theoretically and experimentally. Formulas are developed in a form independent of frequency and operating voltage; these enable the efficiency of a given arrangement to be estimated, and also enable tubes to be designed rapidly with a given efficiency. A tube designed for 50 per cent efficiency at a wavelength of 27 cm and 230-v operating voltage gave a measured efficiency of 49.6 per cent, the highest yet obtained with a drift-space tube. The most effective direction for the beam is at an angle of 1.5° with the axis. The relation between high-frequency power and dc power is also studied.

621.396.645:621.315.592†:537.311.33 1037

The Amplification Observed in Semiconductors—H. F. Mataré. (*Onde élect.*, vol. 30, pp. 469–475; November, 1950.) To obtain a quantitative idea of the phenomenon of transistance, comparative measurements were made at 60 mc of emitter, collector and transfer resistance and capacitance for two mechanically identical Ge crystal triodes of which one, the transistron (see 2978 of 1949), exhibited amplification while the other did not. The results are shown graphically as functions of emitter current, and are discussed. Calculations based on the results yield values for the concentration of impurity centers consistent with Bardeen and Brattain's theory (264 of 1949) that the emitter current is carried by holes. A matrix analysis of the transistron considered as a quadripole is included.

621.396.822 1038

Transit-Time Phenomena in Electron Streams: Part 2—D. K. C. MacDonald. (*Phil. Mag.*, vol. 41, pp. 863–872; September, 1950.) "A density modulated electron stream will suffer amplitude reduction and phase variation with transit time due to the statistical velocity distribution of the electrons. The problem is considered in relation to that of noise generation in a beam due to velocity fluctuation; the analysis developed is then used in examining the variation of space-charge reduction factor (Γ^2) under particular laws of potential distribution which present themselves in physical problems." See also 2408 of 1949.

621.385 1039

Electron Tubes, Vols. 1 & 2. [Book Review]—Publishers: R.C.A. Reviews, Princeton, N. J., 1949, 475 pp. and 453 pp., $2.50 each. (*Electronic Eng.* (London), vol. 22, p. 487; November, 1950.) A collection of papers published by RCA research workers. Volume 1 covers the period 1935–1941 and includes 15 main papers, while the 21 main papers of Volume 2 were published in the period 1942–1948.

MISCELLANEOUS

519.283:658.562 1040

Statistical Methods in Research and Development—L. Lutzker. (PROC. I.R.E., vol. 38, pp. 1253–1257; November, 1950.) 1950 IRE National Convention paper noted in 1559 of 1950 (No. 22).

621.39 Heaviside 1041

The Centenary of the Birth of Oliver Heaviside—L. Bouthillon. (*Onde élect.*, vol. 30, p. 394; October, 1950.) Papers read at a commemorative meeting at the Sorbonne, May, 1950, are noted; these are given in full on pp. 395–415 of the journal and include tributes by L. de Broglie, E. Picault, P. Humbert, S. Colombo, P. M. Prache, L. Bouthillon, E. Appleton (representing the Royal Society), and W. Jackson (representing the Institution of Electrical Engineers).

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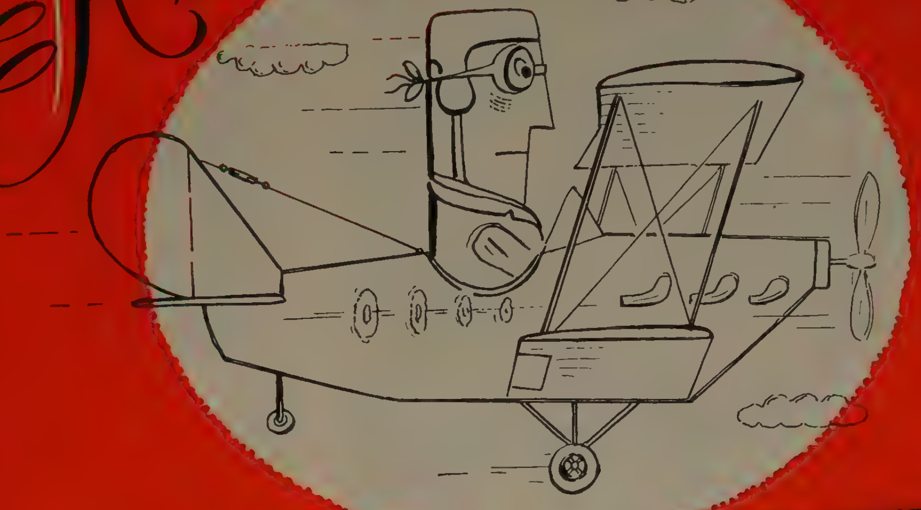


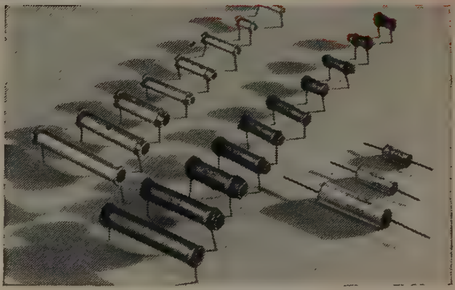
and in producing new navigation and safety devices

MODERN ELECTRONICS LOOK TO HI-Q*

Capacitors • Trimmers • Choke Coils • Wire Wound Resistors

In the air, where space and weight are at a premium, the value of the minute compactness of **Hi-Q** Components is vividly dramatized. Of equal importance is their never failing dependability under any and all conditions. For let a single small unit fail, and life itself may hang in the balance.

The same high engineering standards and unvarying quality which have made **Hi-Q** a leader with producers of aircraft equipment, have found equal favor with other electronic manufacturers. Individual tests of every single component at each stage of production, and as a part of final inspection, insure the precise adherence to specifications, ratings and tolerances. That is one reason why **Hi-Q** is now serving virtually every leading producer of television, communications and other electronic equipment. Another is the ready availability of **Hi-Q** engineers to cooperate in the development of new components to meet specialized needs.



HI-Q TEMPERATURE COMPENSATING CAPACITORS

These high voltage tubular capacitors are available in capacities from 25 mmf. to 250 mmf. Units with working voltage of 3000 V. D. C., are 1.840″ long with .375″ diameter. Those between 500 V. D. C. and 3000 V. D. C. are slightly smaller. All are Durez coated and made of temperature compensating materials.

BETTER 4 WAYS

- ✓ PRECISION
- ✓ UNIFORMITY
- ✓ DEPENDABILITY
- ✓ MINIATURIZATION

JOBBERS—ADDRESS: 740 Belleville Ave., New Bedford, Mass.

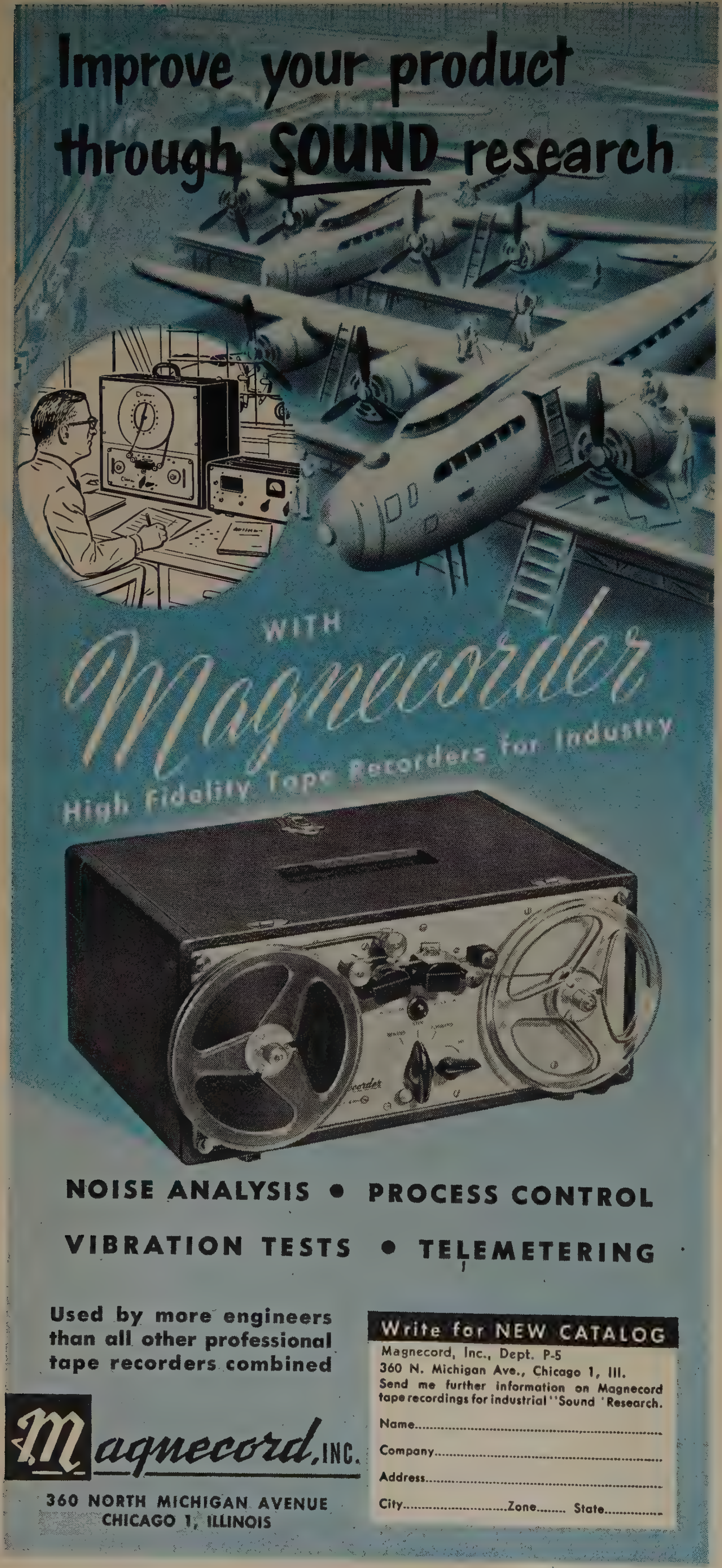
HI-Q*

**Trade Mark Registered, U. S. Patent Office*

Electrical Reactance Corp.
OLEAN, N. Y.

SALES OFFICES: New York, Philadelphia,
Detroit, Chicago, Los Angeles

PLANTS: Olean, N. Y., Franklinville, N. Y.
Jessup, Pa., Myrtle Beach, S. C.



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High Fidelity Tape Recorders for Industry

NOISE ANALYSIS • PROCESS CONTROL

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Used by more engineers than all other professional tape recorders combined

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Send me further information on Magnecord tape recordings for industrial "Sound" Research.

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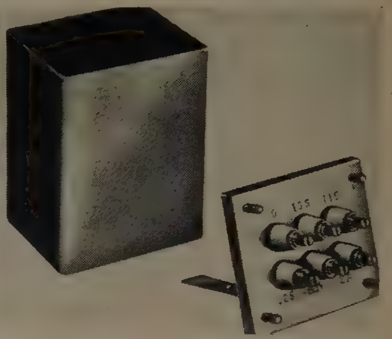
City.............................Zone.......... State...............

News—New Products

These manufacturers have invited PROCEEDINGS information. Please mention your I.R.E. affiliation. readers to write for literature and further technical

Transformer Cans

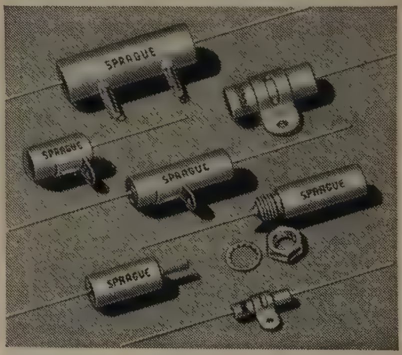
Tooling on all standard sizes of MIL-T-27 transformer cans has been completed and most sizes are already in stock, according to an announcement by **Heldor Metal Products Corp.,** 85 Academy St., Belleville, N. J.



These cans, produced in Heldor's new and enlarged plant, can be supplied with or without brackets, weld studs, blind inserts, compression-type hermetic seal bushings, and stamped ratings. Price lists and complete data can be secured from the company.

Subminiature Paper Capacitors

New ways of mounting subminiature metal-encased paper capacitors, as well as a complete line of subminiature 125° C capacitors, have been announced by the **Sprague Electric Co.,** North Adams, Mass.



Available as standard are hermetically sealed tiny threaded-neck, side-stud and end-stud capacitors, as well as vertical and horizontal bracket mounting units. These new mounting arrangements are intended to help equipment designers overcome vibration and shock problems encountered when mounting capacitors by wire leads in military gear.

These capacitors use Vitamin Q, Sprague's organic polymer capacitor impregnant. These subminiature units are available in voltage ratings from 100 to 1,000 volts dc in both inserted tab and extended foil constructions.

Complete details are available in Bulletin 213A, upon letterhead request only.

(Continued on page 47A)

News—New Products

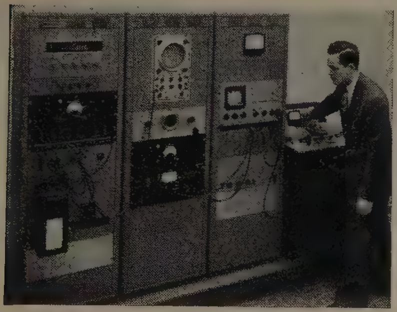
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 22A)

Recorder & Tape Testing Service

Laboratory equipment that can test the performance characteristics of sound recording tape, recorders, and playback units "in a matter of minutes" has been set up in St. Paul, Minn., for use by the industry, (at no charge) it was announced this month.

The equipment and a staff to operate it were provided by **Minnesota Mining and Manufacturing Co.**, 900 Fauquier St., St. Paul 6, Minn., maker of **Scotch** sound recording tape, as a consultant service for the industry.



The three racks of laboratory equipment, plus recorders, and speakers, permit measuring such performance characteristics as output at any frequency, uniformity of output at any frequency, signal-to-noise ratios, dynamic range, wow, flutter, harmonic distortion, intermodulation, and modulation noise.

Included in the equipment are an AM-FM tuner, oscilloscope, wow meter, Ballantine volt meters, dual-channel oscillograph with associated dc amplifiers, two high-fidelity audio amplifiers, two professional quality recorders that operate at any speed from 3¾ to 15 inches per second, and a sonic analyzer for measuring distortion and frequency response and for showing noise spectra.

A special bias circuit was built into the recorders to permit introducing wide variations in bias.

Plug-in Line-Voltage Regulator

For steadier TV pictures despite line-voltage fluctuations, **Clarostat Mfg. Co., Inc.**, Washington St., Dover, N. H., now offers an automatic line-voltage regulator.

This aid to better TV reception, particularly in rural districts or areas experiencing line-voltage fluctuations, is a handy accessory. With male and female Edison connections at either end, it plugs in between the TV set's attachment plug and the outlet. Two models are available: TV-A rated at 300 watts, for sets consuming 200 to 300 watts, and TV-B rated at 375 watts, for sets consuming 300 to 375 watts.

(Continued on page 80A)

SAVE OVER $3,000 on NEW Design
MONOSCOPE AND SYNCHRONIZING SIGNAL GENERATOR SYSTEM

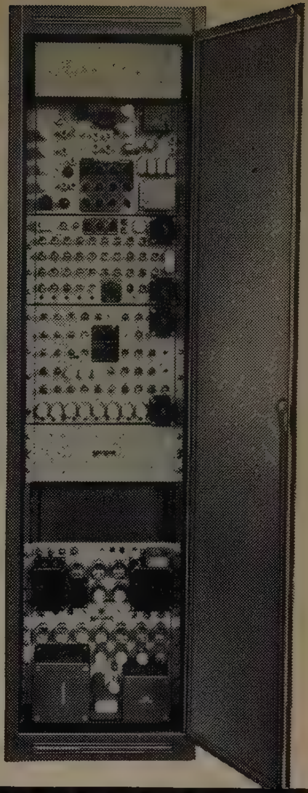
A new high for Stability, Performance and Versatility

TYPE 2300 MONOSCOPE
- Produces standard "Indian Head" test pattern with greater than 450 line resolution.
- Provisions for mixing "sync" in the unit.
- Output polarity Black Negative. Output voltage 2 volts P-P into 75 ohm load. Price $1,200

TYPE 2200 SYNCHRONIZING SIGNAL GENERATOR
- All binary dividers. No blocking tube or locked oscillators. Complete freedom from "rolling" at critical moments.
- Meets all R.T.M.A. and F.C.C. specifications with wide margin to spare.
- Built-in bar and dot generator for sweep linearity checking. Price $1,995

COMPLETE SYSTEM AS SHOWN .. $3,195 F.O.B. PLANT
CBS color standard Monoscope and Synchronizing generator, Type 2301 and 2201, also available.

Write for Type 2200 and 2300 Data Sheets.



TIC Manufacturers of a complete line of TV and Radar Test Equipment
Tel-Instrument Co. Inc
50 PATERSON AVENUE • EAST RUTHERFORD, N. J.

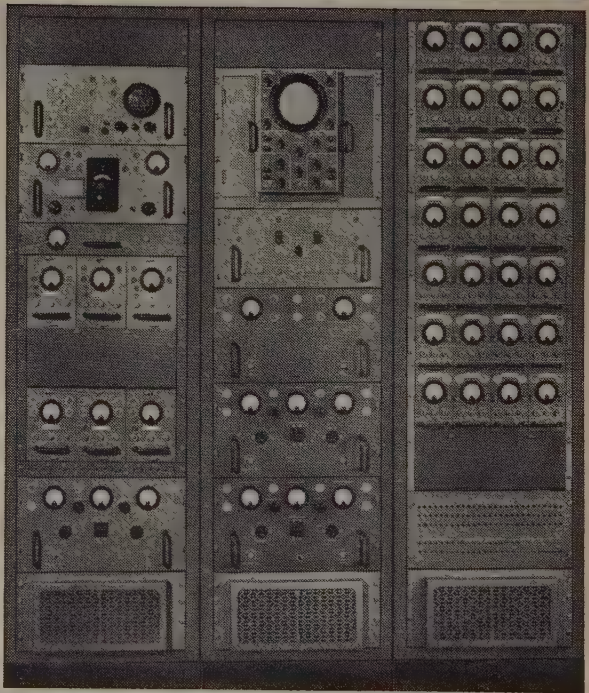
TELEMETER RECEIVING SET
—32 CHANNELS

Carrier frequency:
FM, 215-235 MC/S

Subcarriers: 6
5, FM continuous information
1, FM commutated information, 27 sub-channels

- Automatic Data Separation
- All Electronic
- High Degree of Accuracy and Reliability

For precision equipment in the fields of
RADIO CONTROL & TELEMETERING



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32nd & Walnut Streets • Philadelphia 4, Pa.

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√ Lower losses
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√ Lower operating temperatures
√ Lighter weight . . . smaller sizes
√ Less corona effect

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√ Higher permeability

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FIXED RESISTORS • VARIABLE RESISTORS
IRON CORES • CERAMAG CORES • LINE
and SLIDE SWITCHES • MOLDED COIL
FORMS • GA "GIMMICK" CAPACITORS, etc.

Student Branch Meetings

(Continued from page 46A)

"A Discussion of Desirable Engineering Qualities," by J. A. MacDonald, Vice-President, Ninth District, American Institute of Electrical Engineers; February 22, 1951.

PENNSYLVANIA STATE COLLEGE, IRE-AIEE BRANCH

"Television Networks," by M. E. Strieby, American Telegraph and Telephone Company; February 15, 1951.

UNIVERSITY OF PENNSYLVANIA, IRE-AIEE BRANCH

Election of Officers; March 1, 1951.

PRINCETON UNIVERSITY, IRE-AIEE BRANCH

"Problems Facing a Young Engineer Today," panel discussion by M. Astro, Sperry Gyroscope Company, M. Carpenter, RCA Laboratories, R. Hartman, Remington Arms Company, A. Westneat, Applied Science Corporation, and G. Sikes, Princeton University; February 15, 1951.

PURDUE UNIVERSITY, IRE BRANCH

"Industrial Television," by R. C. Webb, Iowa State College; February 28, 1951.

RUTGERS UNIVERSITY, IRE-AIEE BRANCH

"Problems Facing a Young Engineer Today," panel discussion by M. Astro, Sperry Gyroscope Company, M. Carpenter, RCA Laboratories, R. Hartman, Remington Arms Company, A. Westneat, Applied Science Corporation, and G. Sikes, Princeton University; February 15, 1951.

SAN JOSE STATE COLLEGE, IRE BRANCH

"A 20 Kw Tetrode," by C. E. Murdock, Eitel-McCullough, Incorporated; February 12, 1951.

SEATTLE UNIVERSITY, IRE BRANCH

Film: "Industrial Electronic Heating"; February 14, 1951.

Tour through Television Studios KING-TV; February 27, 1951.

SOUTHERN METHODIST UNIVERSITY, IRE-AIEE BRANCH

Election of Officers and talk, "Unlimited Opportunities for Engineers," by C. B. McEacheron, General Electric Company; February 26, 1951.

SYRACUSE UNIVERSITY, IRE-AIEE BRANCH

Election of Officers and talk, "Radar Engineering," by H. F. Mayer, General Electric Company, February 27, 1951.

UNIVERSITY OF TEXAS, IRE-AIEE BRANCH

"Power Development in Texas," by R. R. Krezdorn, University of Texas; February 19, 1951.

"Proposed Course on Analogue Computers," by A. R. Teasdale; University of Texas; March 5, 1951.

Film: "Television Today"; March 19, 1951.

UNIVERSITY OF TOLEDO, IRE-AIEE BRANCH

General Discussion; February 22, 1951.

Films: "What Is Electricity" and "Electronics At Work"; March 8, 1951.

UNIVERSITY OF TORONTO, IRE-AIEE BRANCH

Election of Officers and talk, "Industrial Electronic Control," by J. T. Thwaites, Canadian Westinghouse Company, Limited; February 5, 1951.

"Ontario Provincial Police Radio System," by J. E. Reid, University of Toronto; February 27, 1951.

TUFTS COLLEGE, IRE-AIEE BRANCH

"New England Power Interconnection," by Robert Brant, New England Power and Service Company; December 13, 1950.

"Radio-Frequency Heating," by M. L. White, Westinghouse Electric Corporation; February 21, 1951.

(Continued on page 64A)

SOLVE YOUR RADAR CALL PAUL J. PLISHNER SONAR SUPPLY PROBLEMS

3000 Mc BENCH TEST PLUMBING

SIGNAL GENERATOR, using 417A klystron, 2700-2900 mc. Output approx. 50 mw, 115 vac power supply. With tubes, new $425

10 CM RF PACKAGE, using 2J22 magnetron, freq. range 3267-3333 mc, complete with power supply and pulser giving apx. 20 kv @ 30 A, 1 usec, 1000 PPS. Power output 285 kw. ⅞" rigid coax plumbing thruout. Uses 417A klystron mixer, 6AC7 preamp. Pulser is 715 B hard tube. Complete RF unit, pulser unit, receiver front end, new, with tubes. Requires 115v, 400 cy ac primary source $385.00

RECEIVER POWER SUPPLY for GL 446 type lighthouse tubes (2C40, etc.) 115 vac, 60 cycles. Panel mounting. Less tubes $32.50

10 CM DISH AND DIPOLE ASSY; apx. 30" parabola, with 300 deg rotating mechanism, and approx. 10 deg. tilt mechanism, Operating from 24 vdc. With selsyn $85

10 CM LOW POWER tunable load with circ. cover $225

COAX. CRYSTAL MOUNT, type N connectors $17.50

RT-39/APG-5 10 cm. lighthouse RF head c/o Xmtr.-Recvr-TR cavity, compl. recvr & 30 MC IF strip using 6AK5. (2C40, 2C43, 1B27 lineup) w/Tubes.

721A TR BOX complete with tube and tuning plungers ..$12.50

McNALLY KLYSTRON CAVITIES for 707B or 2K28. Three types available $4.00

F 29/SPR-2 FILTERS, Type "N" input and output $12.50

WAVEGUIDE TO ⅞" RIGID COAX "DOORKNOB" ADAPTER CHOKE FLANGE, SILVER PLATED BROAD BAND $32.50

WAVEGUIDE DIRECTIONAL COUPLER, 27 db. Navy type CABY 47 AAN, with 4 in. slotted section $32.50

SQ FLANGE to rd choke adapter. 18 in. long OA 1½ in. x 3 in. guide, type "N" output and sampling probe $27.50

AN/APR5A 10 cm antenna equipment consisting of two 10 cm waveguide sections, each polarized 45 degrees $75.00 per set.

POWER SPLITTER: 726 Klystron input dual "N" output $5.00

MAGNETRON COUPLING FOR TYPE 720 MAG. to 1½" x 3" Waveguide $35.00

10 CM WAVEMETER WE type B43549 Transmission type, Type N Fittings Veeder Root Micrometer dial. Gold Plated W/Calib. Chart P/o Freq. Meter X66404-A. New $99.50

AS14A/AP-10 CM Pick up Dipole with "N" Cables $4.50

LHTR. LIGHTHOUSE ASSEMBLY Part of RT39 APG 5 & APG 15. Receiver and Trans Cavities w/assoc. Tr Cavity and Type N CPLG. To Recvr. Uses 2C40, 2C43, 1B27, Tunable APX 2400-2700 MCS. Silver Plated $49.50

BEACON LIGHTHOUSE cavity 10 cm with miniature 28 volt DC FM motor. Mfg. Bernard Rice ....$47.50 ea.

MAGNETRON TO WAVEGUIDE Coupler with 721A Duplexer Cavity, gold plated $45.00

⅞" RIGID COAX—⅜" I.C.

⅞" RIGID COAXIAL TUNING STUBS with vernier stub adjustment. Gold Plated $17.50

⅞ RIGID COAX. ROTARY JOINT. Pressurized. Sperry #810612. Gold Plated $27.50

DIPOLE ASSEMBLY. Part of SCR-584 ....$25.00 ea.

ROTARY JOINT. Part of SCR-584 ....$35.00 ea.

RIGHT ANGLE BEND, with flexible coax. output pickup loop $8.00

SHORT RIGHT ANGLE BEND, with pressurizing nipple $3.00

RIGID COAX. to flex coax. connector $3.50

STUB-SUPPORTED RIGID COAX, gold plated 5' lengths. Per length $5.00

RT. ANGLES for above $2.50

RT. ANGLE BEND 15" L. OA $3.50

FLEXIBLE SECTION. 15" L. Male to female $4.25

MAGNETRON COUPLINGS to ⅞" rigid coax. with TR pickup loop, gold plated $7.50

FLEX. COAX. SECT. Approx. 30 ft. $16.50

CG 54/U—4 foot flexible section ⅜" IC pressurized $15.00

⅞ RIGID COAX. Bead Supported $1.20

SHORT RIGHT ANGLE BEND $2.50

6000 Mc to 8500 Mc BENCH TEST PLUMBING

1½" x ¾" Waveguide

Klystron Mount. DB356 complete with shield and tunable termination $125.00

Flap Attenuator. DB361 $45.00

Variable Stub Tuner $90.00

Wvgd. to Type "N" Adapter $18.50

Wavemeter Tee. DB352 ..$32.50

Magic Tee $80.00

Directional Coupler, two hole 25DB coupling, type "N" output $25.00

Precision Crystal Mount. Equipped with tuning slugs and tunable termination $125.00

Tunable Termination. Precision adjust $70.00

Low Power Load $35.00

4000 to 6000 Mcs BENCH TEST PLUMBING

2" x 1" Waveguide

Flap Attenuator $48.00

Variable Stub Tuner and Low Power Termination $48.00

Wavemeter Tee $48.00

Adapters: Choke to choke $18.00
Cover to cover $14.00
Choke to cover $16.00

Waveguide to Type "N" Adapter $45.00

Directional Coupler. Two hole type "N" output $48.00

Klystron Mount. Equipped with tunable termination and micrometer adjust. Klystron antenna tuning $110.00

Crystal Mount. Equipped with tunable termination and micrometer adjust crystal tuning $125.00

Tunable Termination. Precision adjust $90.00

23,000 to 27,000 Mc BENCH TEST PLUMBING

½" to ¼" Waveguide

Low Power Load $20.00

Shunt Tee $35.00

Waveguide Lengths, 2" to 6" long, gold plated with circular flanges and coupling nuts $2.25 per inch

APS-34 Rotating Joint ..$49.50

Right Angle Bend E or H Plane, specify combination of couplings desired $12.00

45° Bend E or H Plane, Choke to cover $12.00

Mitered Elbow, cover to cover $4.00

TR-ATR-Section. Choke to cover [illegible]

Flexible Section 1" choke to choke $5.00

"S" Curve Choke to cover $4.50

Adapter, round to square cover $5.00

Feedback to Parabola Horn with pressurized window $27.50

90° Twist $10.00

"K" Band Directional Coupler $49.50 ea.

APS-2
APS-3
APS-4
APS-6
APS-6A
APS-10
APQ-13
APS-15
APS-31
CPN-8
CEXH
FD MK 4
MARK 10
SA
SC
SD
SE
SF
SG
SJ
SK
SL
SM
SN
SO
SQ
SW
SCR 518
SCR 520
SCR 533
SCR 545
SCR 663

MAGNETRONS

Tube
2J27
2J31
2J21 A
2J22
2J26
2J32
2J37
2J38
2J39
2J40
2J49
2J34
2J61
2J62
3J31
5J30
714AY
718DY
720BY
720CY
725-A
730-A
728
700
706

KLYSTRONS

723A
707B
417A
2K41

TEST SETS

TS 12
TS 33
TS 35
TS 36
TS 45/APM3
TS 62 3CM
TS 108

SCR 584 PARTS AVAILABLE

BC1056A
BC1058A
BC1086B
RA71A
BC1090A
BC1090B
BC1096A
BC1[illegible]
BC105BB
BC1094A
BC1088A

SONAR SYSTEMS

QBF
QBG
QC
QCJ
QCL
QCO
QCS
QCU
WEA

8500 Mc to 9600 Mc BENCH TEST PLUMBING

1" x ½" Waveguide

3 CM SIGNAL GENERATOR and thermistor bridge, using 723AB oscillator, calibrated variable attenuator, direct reading power meter; req. 115 vac. 60 cy. power supply. Complete with tubes $425

3 CM SLOTTED LINE, with probe, and including accessories, i.e. low power load, adaptors, etc. TS 12/Unit 2 ......$385

AN/APS-15A "X" Band compl. RF head and modulator, incl. 725-A magnetron and magnet, two 723A/B klystrons (local osc. & beacon), 1B24, TR, recvr-ampl. duplexer, HV supply, blower, pulse xtmr. Peak-Pwr Out: 45 KW apx. Input: 115, 400 cy. Modulator pulse duration .5 to 2 micro-sec. apx. 13 KV Pk Pulse, Compl. with all tubes incl. 715-B, 829B, RKR 73, two 72's. Compl. pkg., new $375

COMPLETE 3 CM RADAR SYSTEM EQUIPMENT

40 KW PEAK TRANSMITTER, pulse modulator, receiver, using 723AB, power supply operating from 115V 800 Cycle, antenna system. Complete radar set neatly packaged in less than 16 cubic feet, less rcvg type tubes, but incl. all others, in used but excellent condition—This price for laboratories, schools, and experimental purposes only $350

MAKE SURE YOU SEE OUR SPECIAL AD NEXT MONTH

2J42 PULSE MODULATOR, 14 Kw max. rating, 7 kw min. Plate voltage pulsed 5.5 kv, 6.5 amp, .001 duty cycle, 2.5 usec pulse length max, filament 6.3 v, .5 amp. Includes magnetron mtg. and blower. Requires 3C45 and 2-3B24 ....$75.00

3 CM SECTOR SCANNING ANTENNA, 18" dish, cutler feed dipole, 24 vdc drive motor $75.00

APS-3 RADAR, new and complete, using 725A magnetron $950.00

TS 36 X band power meter 1¼" x ⅝" waveguide; thermistor bridge with indicating meter, complete $175.00

TS 33 X band coax. freq. meter/with resonance indicating meter crystal mount, type N fitting $225.00

Wavemeter. 8500 to 9460 Mcs., with calibration. Micrometer adjust head. Reaction type $85.00

90 Degrees Elbows. E or H plane, 2½" radius $12.50

90 Degree Twist. 6" long..$8.00

Bulkhead Feed-Thru Assembly $15.00

Pressure Gauge Section 15 lb. gauge and press nipple ...$10.00

Pressure Gauge. 15 lbs. ..$2.50

Dual Oscillator-Beacon Mount. P/O APS10 Radar for mounting two 723A/B klystron with crystal mts. matching slugs, shields $42.50

Dual Oscillator, Mount. (Back to back) with crystal mount, tunable termination attenuating slugs $18.50

Directional Coupler. UG-40/U Take off 20 DB $17.50

Directional coupler, APS-6 type "N" take off 20 DB calibrated $17.50

Rotary Joint Choke to Choke $10.00

2K25/723 AB Receiver local oscillator Klystron Mount, complete with crystal mount. Iris coupling and choke coupling to TR $22.50

TR-ATR Duplexer section for above $8.50

CU 105/APS 31 Directional Coupler 25 DB $25.00

723AB Mixer—Beacon dual Osc. Mnt. w/xtal holder......$12.00

TR-ATR Sect APS 15 for 1B24 w/724 ATR cavity w/1B24 & 724 Tubes. Complete.....$21.00

Stabilizer Cavity with bellows $21.50

3 cm. 180° bend, with pressurizing nipple .... ea. $6.00

3 cm. 90° bend, 14" long 90° twist with pressurizing nipple ea. $6.00

3 cm. "S" curve 18" long ea. $5.50

3 cm. "S" curve 6" long ea. $3.50

3 cm. right angle bends. "E" plane 18" long cover to cover ea. $6.50

3 cm. Cutler feed dipole. 11" from parabola mount to feed back ....ea. $8.50

3 cm. directional coupler. One way waveguide output ea. $15.00

Circular Choke Flanges, solid brass ....55¢

Sq. Flanges. Flat Brass ea. 55¢

APS-10 TR/ATR Duplexer section with additional iris flange [illegible]

"X" Band Preamplifier, consisting of 2-723 A/B local oscillator-beacon feeding waveguide and TR/ATR Duplex sect. incl. 60 pic. IF amp. $47.50

15 Deg Bend 10" choke to cover $4.50

5 Ft. Sections choke to cover. Silver plated $14.50

18" Flexible Section $17.50

TR Cavity for 724 A TR Tube $3.50

724 TR Tube (41 TR 1) ..$2.50

SWR Meas. Section, & L with 2 type "N" output probes MTD full wave apart. Bell size guide. Silver plated $10.00

Rotary joint with slotted section and type "N" output pickup $17.50

Waveguide Section 12" long choke to cover 45 deg. twist & 2½" radius, 90 deg. bend. $4.50

Twist 90 deg. 5" choke to cover w/press nipple $6.50

Waveguide Sections 2½ ft. long silver plated with choke flange $5.75

Rotary joint choke to choke with deck mounting $17.50

3 cm mitred elbow "E" plane unplated $12.00

1¼" x ⅝" WAVEGUIDE

Tunable Termination. Precision adjust $65.00

Low Power Termination..$25.00

Magic Tee $45.00

90 Degree Elbows, E or H plane $12.50

Waveguide Lengths. Cut to size and supplied with 1 choke, 1 cover, per length ..$2.00 per ft.

BI Dir-Coupler WG output calibrated —25 db nominal..$17.50

Flex sections, 12" Rubber Coated $14.50

Mitred Elbow H Plane UG51-UG52 ....$12.00

6" St. sect. choke to choke $3.50

APQ 13 Constant Z Rotat Jnt. $22.50

CG 98B/APQ 13 12" Flex. Sect. 1¼" x ⅝" OD $10.00

Wave Gd Run 1¼" x ⅝" Gd. consists of 4 ft. sect. w/RT angle bend on one end. 2" 45 deg bend on other end $8.00

X Band Wave Gd. 1¼" x ⅝" O.D. 1/16" wall aluminum Per ft. 75¢

Slug. Tuner Attenuator W.E. guide. Gold Plated $6.50

WAVEGUIDE

½" x ¼" ID	$1.00 per foot
1" x ½" OD	$1.50 per foot
⅝" x 1¼" OD	$1.65 per foot
⅝" x 1¼" OD Aluminum	.75 per foot
1½" x 3" OD	$3.00 per foot
2½" 3" OD	$3.50 per foot
1" x ½" OD Flexible	$4.00 per foot
⅞" rigid coax ⅜" IC	$1.20 per foot
(Available in 10FT to 15 ft. lengths or smaller.)	$8.50 each

All merch. guar. Mail orders promptly filled. All prices, F.O.B., N.Y.C. Send Money Order or Check. Only shipping charges sent C.O.D. Rated Concerns send P.O.

MIN. ORDER $3.00 **COMMUNICATIONS EQUIPMENT COMPANY** MIN. ORDER $3.00

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News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 47A)

Plant Expansion

Pyramid Electric Co., 155 Oxford St., Paterson, N. J., recently purchased the Solar Mfg. Co., plant at 1445 Hudson Blvd., North Bergen, N. J. The plant has 120,000 square feet of factory space and is located on a four-acre tract. Much of the original equipment was also purchased, and many of the old Solar employees will be employed here.

Closed Circuit TV Transmitter

The Dumitter, just announced by the **Television Transmitter Div., Allen B. Du-Mont Laboratories, Inc.**, Clifton, N. J., permits TV camera signals to be distributed to a large number of standard TV receivers, over connecting cables.

The Dumitter is a compact, completely portable unit. It takes the composite video signal from any standard TV camera chain, and feeds it via a single coaxial cable to the antenna terminals. A carrier signal of the frequency of either Channel 2 or 3 (optional on the Dumitter controls) is used. Up to 125 receivers can be driven simultaneously, with transmission of over several thousand feet.

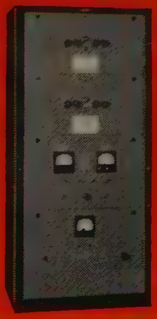
The antenna lead-in is disconnected from the receiver, while the Dumitter signal is being received, by switching from Dumitter line to antenna lead-in, permitting the receiver to function on either closed-circuit or standard telecasting at will. No circuit alterations or component changes are required.

Since the signals travel through coaxial cables, reception is free from outside interference. No license is required, since the transmitter does not radiate.

(Continued on page 82A)

Collins 231D high frequency Autotune* transmitter. The power output is 2.5 to 5 kilowatts, depending on frequency and type of emission.

Collins 16F high frequency Autotune* transmitter. The power output is 300 watts voice or MCW, 500 watts CW.



Collins 716A frequency shift receiving terminal for reception and conversion of single channel or multiplex printer transmissions. Top to bottom: two 51N-4 frequency shift receivers, 706A-2 frequency shift converter, and 707A-1 power supply.

RADIO - CANNY ARINC EMPLOYS COLLINS EQUIPMENT ON THE GROUND

REAR VIEW

FRONT VIEW

Collins 709D frequency shift keyer. A very simple, dependable unit for adapting existing transmitters to frequency shift operation.

Collins 51N-2 high frequency radiophone receiver.

"Canny" means *careful in determining or acting; prudent; knowing; thrifty.* Aeronautical Radio Incorporated is all of that, particularly when it comes to radio communications for the airlines.

So it is significant that ARINC chose Collins equipment of the types shown on this page for both its Pacific and Caribbean networks.

The Pacific net includes ground based facilities at Los Angeles, San Francisco, Seattle, Anchorage, Shyma (Aleutians), Honolulu, Okinawa and Tokyo. This net serves Pan American, Northwest, United, British Overseas, Trans Pacific, Philippine, Chinese National and Air France.

The Caribbean net is based at Houston, New Orleans, Miami, Mexico City, Havana and San Juan. Its facilities are used by Pan American, AAL de Mexico, Eastern, Braniff, Chicago and Southern, LAV, British Overseas, KLM, Avianca and Panagra.

In both areas ARINC conducts large operations connected with the airlines weather, en-route communications and operational dispatches. Collins equipment is used for point-to-point phone, CW and typewriter transmission and reception, and ground-to-air voice communications.

Write us about your requirements in ground based radio communications equipment.

*Reg. U. S. Pat. Off.

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COLLINS RADIO COMPANY, Cedar Rapids, Iowa

11 West 42nd Street, NEW YORK 18 2700 West Olive Avenue, BURBANK

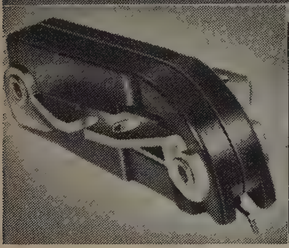
Introducing...
SHURE BROTHERS, INC.
"Direct Drive"

A new SHURE family of crystal and ceramic fine-groove and standard cartridges

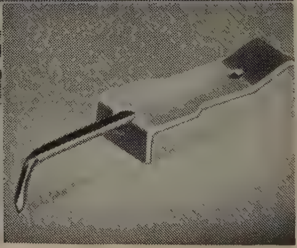
SPECIAL CRYSTAL MODEL W31AR and Ceramic Model WC31AR are unsurpassed for replacement of RCA "45" R.P.M. Changer Cartridges (ideal for 33⅓ R.P.M. too)!

Unique needle design provides the easy needle replacement everybody has been looking for—and protects cartridge from mechanical shock.

THESE NEWLY DEVELOPED CARTRIDGES PROVIDE:
Easy Cartridge Installation • Maximum Fidelity • Easy Needle Replacement


Universal, light-weight aluminum mounting ears will fit either ½" or ⅝" mounting.

Response-frequency characteristic designed to complement record response for maximum fidelity and minimum noise.


New, specially designed needle with broad shank and finger-nail grip bar. Long-life osmium point.

THIS NEWLY DEVELOPED SERIES OF CARTRIDGES is the last word for first-place reproduction at low cost. So easy to install, the Serviceman will ask for them over and over again. High vertical compliance of the especially designed needle protects the crystal and ceramic elements from "drop-shock" damage.

Model	Type	List Price	Output Voltage	Needle Force	Shure Needle No.	Code
W31AR	Crystal 33⅓ & 45 R.P.M.	$6.50	2.1 V	7 grams	A53MG	RUGEB
WC31AR	Ceramic 33⅓ & 45 R.P.M.	6.50	.65 V	7 grams	A53MG	RUGED
WC33B	Ceramic 78 R.P.M.	6.50	.75 V	9 grams	A52A	RUGEL
W36B	Crystal All-Purpose	6.50	2.5 V	9 grams	A56U	RUGEN
WC36B	Ceramic All-Purpose	6.50	.7 V	9 grams	A56U	RUGER

Shure Patents Pending.
Licensed Under Patents of Brush Development Co.

SHURE

SHURE BROTHERS, Inc. ★ Manufacturers of Microphones and Acoustic Devices

225 W. Huron St., Chicago 10, Illinois • Cable Address: SHUREMICRO

News—New Products

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(Continued from page 80A)

TV Field Strength Meter

The **Simpson Electric Co.,** 5200 W. Kinzie St., Chicago 44, Ill., has introduced a television field-strength meter which will measure television signals in any locality and in all types of installations. The new engineering design which has given special consideration to fringe area applications includes such functions as location of maximum signal areas, antenna orientation, comparison of antenna systems, adjustment of boosters, and checking antenna and lead-in installations.

Simpson
TV FIELD STRENGTH METER

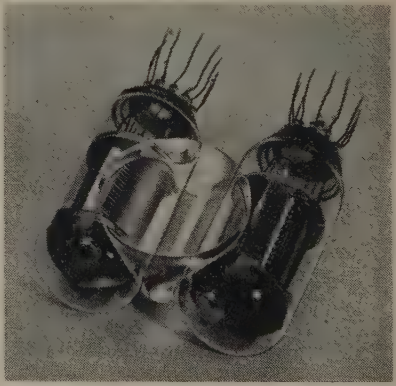
Model 488 incorporates a 12-channel television tuner with each channel separately adjustable, for maximum flexibility and uniform results.

There are four ranges of sensitivity: 50-, 500-, 5,000-, and 50,000-microvolt range.

A phone jack is included for making audible tests so that the operator can quickly identify the type of signal being measured.

Crystalline and Plastic Phosphors

Tracerlab, Inc., 130 High St., Boston 10, Mass., now has available two versatile and efficient phosphorescent materials for use in scintillation detector units. One is the synthetically grown hydrocarbon crystal known as Stilbene, and the other is Tracerlab's solid plastic phosphor.



Stilbene is nonvolatile and is stable with respect to the water content of the at-

(Continued on page 84A)

IN BUSINESS **LENZ** SINCE 1904

Wire for Defense Projects!

HOOK-UP WIRES and CABLES for COMMUNICATIONS EQUIPMENT and ELECTRONIC INSTRUMENTS

FOR almost a half century Lenz has been producing insulated Wires and Cables for the Communications Industries, wires that are engineered and designed under high quality standards.

Now, Lenz is prepared to furnish hook-up wire and cables for defense projects, conforming to Government specification JAN-C-76 TYPES WL, SRIR and SRHV.

These Thermo-Plastic Insulated Wires, with or without Lacquered Braids, and the cables constructed of same, are available for use in Communications Equipment and Electronic Instruments.

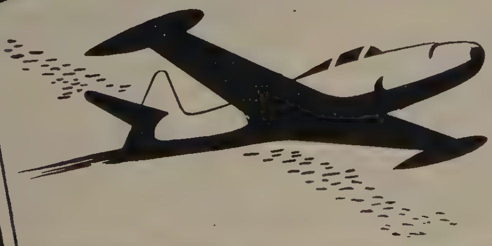
For a dependable source for your wire and cable requirements, consult Lenz.

CONFORMING TO
JAN-C-76
TYPES WL, SRIR and SRHV

ON THE SEA

ON LAND

IN THE AIR



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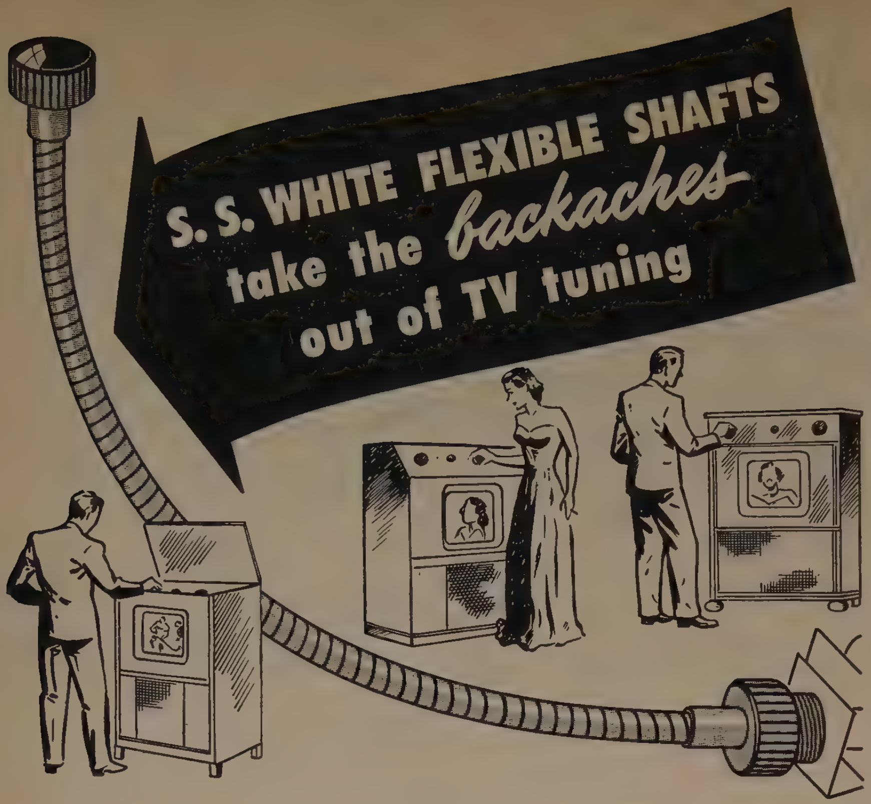
1751 No. Western Ave. • Chicago 47, Illinois

LENZ



Usually the tuning knobs on TV sets are down below the screen where you have to bend, stoop or squat to operate them.

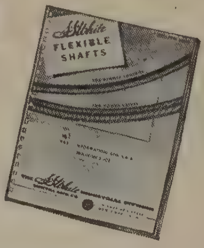
It's a simple matter to put an end to this "backache" type of tuning. Just couple the knobs to the tuning elements with S.S.White remote control flexible shafts. This will allow you to place the knobs on top of the set where they are easily seen and operated from a comfortable standing position. Not only that, the shafts allow the knobs to be mounted in any desired arrangement to conform with the cabinet design.

S.S.White engineers will be glad to cooperate with you in working out the details of any flexible shaft application. Call them in today—there's no obligation.

S.S.White MAKES IT RIGHT

WRITE FOR NEW BULLETIN 5008

It contains the latest information and data on flexible shafts and their application. Write for a copy today.



THE S.S.White INDUSTRIAL DIVISION
DENTAL MFG. CO.
Dept. G 10 East 40th St.
NEW YORK 16, N. Y.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 82A)

mosphere. Precisely formed phosphors of up to one inch in any dimension are readily machined from the colorless, optically clear, single crystal masses of Stilbene. The violet light emitted by this phosphor has the required intensity to operate modern counting equipment with efficiency, and uniform response to radiation results from all samples of this crystal. The time constant of Stilbene is less than 10^8 seconds, and it is less dependent upon temperature than most other phosphors.

To supply a substitute for large costly phosphors, Tracerlab has developed an inexpensive luminescent plastic which can be molded into a large variety of shapes. Thus for instance, the plastic phosphor can be molded so as to embed two 1P21 photomultiplier tubes operating in coincidence to reduce multiplier noise background, as is shown in the illustration.

This phosphor is essentially a solution of Terphenyl in a styrene monomer, the whole mass being polymerized into a solid. The resulting clear mass resembles ordinary polystyrene in both its physical and chemical properties. The phosphor pulses of this plastic are about one-quarter as large as those of Stilbene when viewed with the S9 spectral response of a 5819 tube. Pulse duration is of the same order of magnitude as that of the organic crystalline phosphor, i.e., less than 10^8 seconds.

Linear Amplifier for Proportional Counting

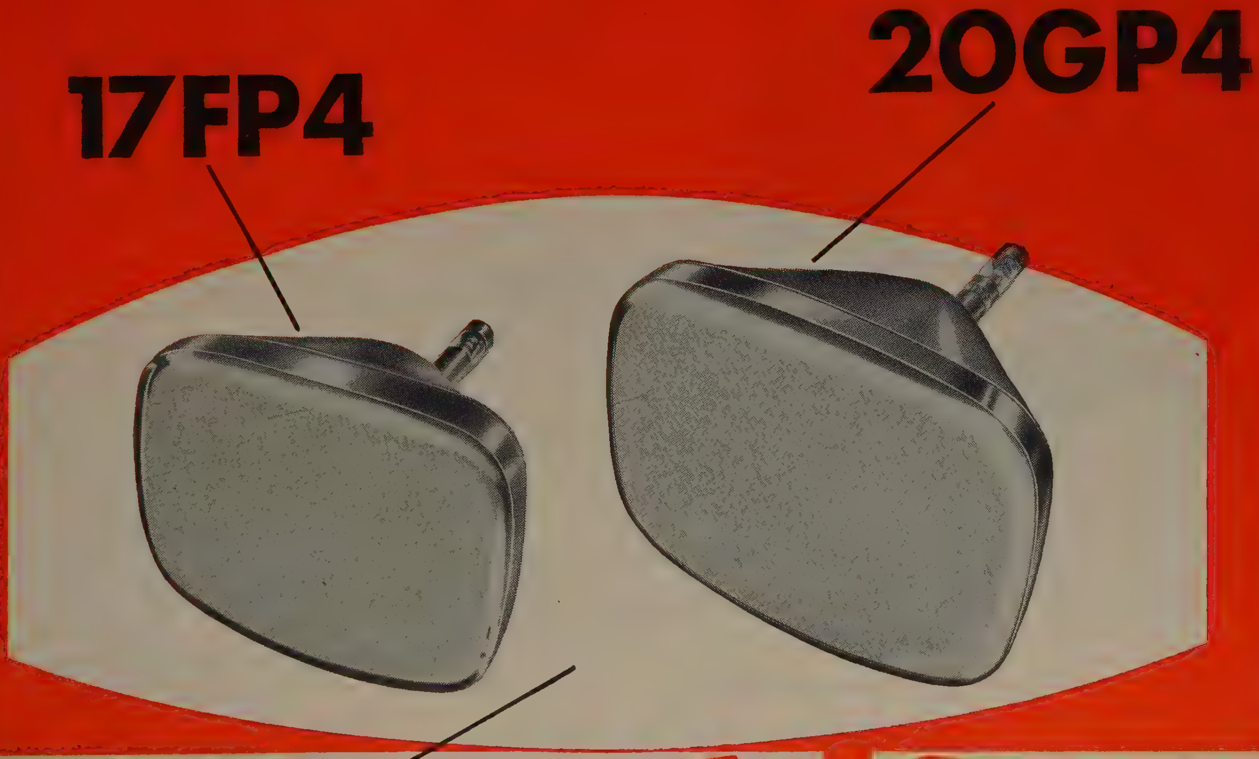
In order for users to adapt nuclear Geiger-Mueller scalers to proportional counting, a new Model 1061 linear amplifier has been announced by **Nuclear Instrument and Chemical Corp.,** 223 W. Erie St., Chicago 10, Ill.

This instrument is connected between the detector and a nuclear scaler, and provides convenient sensitivity adjustment, calibrated in millivolts, with a choice of 1- or 10-millivolt maximum sensitivity. The instrument has a flat frequency response of 10,000 cps to 1.5 Mc. A set of oscilloscope terminals are located on the front panel, while all other connections are on the rear. The instrument is so designed that the scaler may operate independently without disconnecting it from the amplifier.

(Continued on page 86A)

THE FINEST IN ELECTROSTATIC FOCUSING

Teletrons*



complete
engineering data
on request

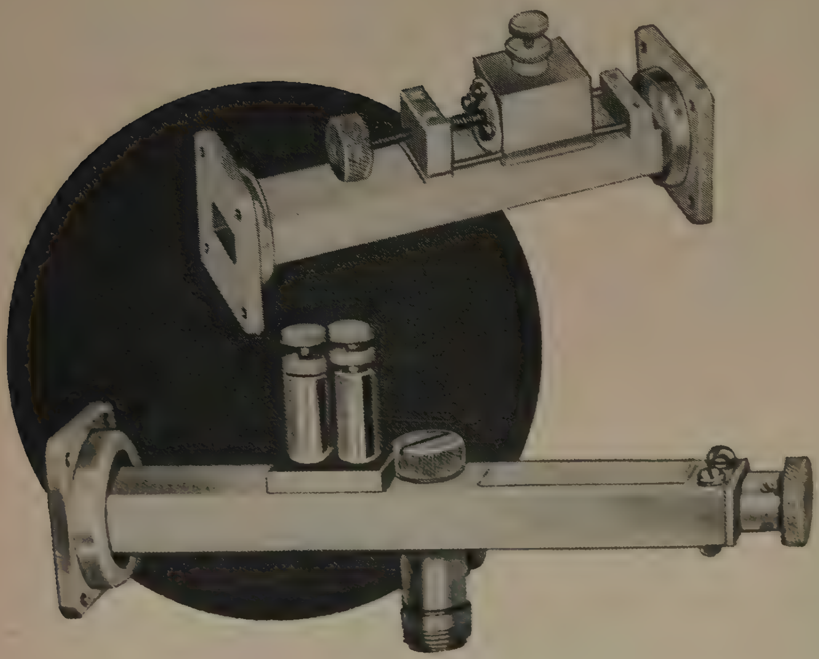
DUMONT

TUBE DIVISION, ALLEN B. DU MONT LABORATORIES, INC., CLIFTON, N. J.

*Trade-mark.

KINGS

Microwave Equipment



KINGS proudly introduces a new and complete line of microwave equipment. Many improvements in design and construction are your assurance of the finest in precision instrumentation. Our engineering department is ready to cooperate on your most exacting microwave and research problems. Inquiries are invited.

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an affiliate of Kings Electronics Company, Inc.

News—New Products

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(Continued from page 84A)

100-A Dynamic Analyzer

The 100-A, dynamic analyzer, manufactured by **Industrial Control Co.**, 1452 Undercliff Ave., New York 52, N. Y., is an instrument that facilitates the measurement of frequency and transient response of low-frequency systems by electrical methods. It is particularly applicable to the servomechanism, either as a closed loop, or in its individual components.

Of chief interest is the flexibility of the device. The generating mechanics are mounted on a separate shock-mounted horizontal chassis, which is easily accessible thru panel cutouts in the case. The elements themselves are mounted with breadboard apparatus. A vertically mounted electronic chassis furnishes the power for the speed drive, the excitation voltages, etc. This construction allows the user to quickly modify the unit for some special test, by changing gear ratios, adding signal generating components, etc.

The range of modulating frequencies is from 0.1 to 50 cps for transfer function tests. Phase measurements can be made with accuracies of ±2°. For the transient tests, the damped natural frequency and the height of the first overshoot can be measured.

Plug-In Non-Interchangeable Base and Sockets

Alden Products Co., 17 N. Main St., Brockton, Mass. announces the addition of the Alden "20" noninterchangeable base and sockets to its line of plug-in components.

(Continued on page 87A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

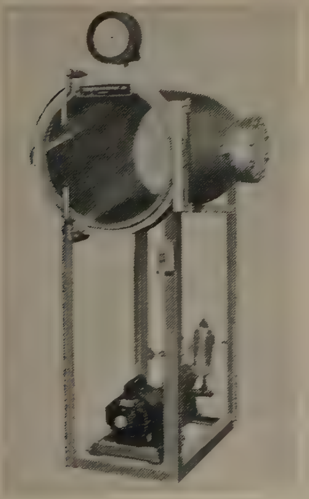
(Continued from page 86A)

The new 20-pin base, with matching sockets, was designed specifically for plug-in unit construction. The design of the base eliminates many of the difficulties encountered with conventional type bases. There is no molded center boss to break, pins are strong and stubby, do not bend or break out; by selecting variations of pin layout of less than 20 pins, critical voltages, and frequencies can be isolated and the base can be made noninterchangeable so that it will mate only with correct socket; therefore prevents mismating and the danger of burned out units. The scope of the base for mounting electronic components is wide, open units, shielded units, relays, filters, terminal cards for wiring complete assemblies, all mount easily with standard production tools and become compact plug-in units.

Vacuum Test Chamber

A vacuum test chamber, complete with pump and direct reading altitude gauge designed to test component parts performance at various altitudes or degrees of vacuum, is announced by **Tenney Engineering, Inc.**, 26 Avenue B, Newark 5, N. J.

By means of a pressure regulating valve, the chamber is capable of being evacuated and held at any desired equivalent altitude up to 60,000 feet, it is claimed.



The drum head is of welded construction; flanged circular door is heavy glass complete with sealing ring and latches for vacuum tight fit. A 1-inch utility port is provided for electrical leads etc. Inside dimensions are: 19½ inches diameter×30 inches plus additional space in drum head. The chamber comes equipped with pump in one unit or as a table top model, consisting of chamber only with vacuum pump unmounted for installation under bench. All equipment is factory-tested prior to shipment.

(Continued on page 88A)

KINGS
COAXIAL CONNECTORS

UG-59A/U
UG-21B/U
UG-222/U
UG-174/U
UG-290/U
UG-185/U
UG-88/U
UG-57B/U
UG-27B/U
UG-483/U
PL-259
UG-58/U
SO-239
UG-100A/U

preferred by engineers everywhere

From coast-to-coast, engineers in all fields look to Kings Electronics for the finest coaxial connectors. Special problems in design and fabrication receive the wholehearted cooperation of Kings own engineering department. For precision-made, pressurized R. F. Connectors call on Kings — the leader. Quotations on request.

KINGS Electronics

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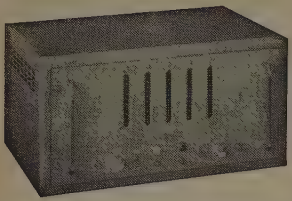
IN CANADA: ATLAS RADIO CORP., TORONTO

A Better WAY...

for LABORATORY OR PRODUCTION LINE!



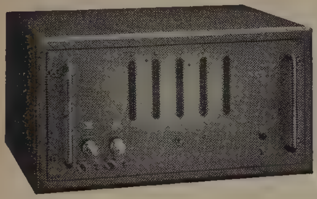
EPUT* for

- ELECTRONIC TACHOMETRY
- FREQUENCY MEASUREMENTS
- HIGH SPEED COUNTING

THE BERKELEY EVENTS-PER-UNIT TIME* Meter will automatically count and display the number of events that occur during a precise one second interval at rates up to 100,000 per second. Accuracy is ± one event. These events may be any mechanical, electrical, or optical occurrences regularly or randomly spaced that can be converted into changing voltages. Thus the EPUT becomes an extremely flexible tool which may be used as a precision electronic tachometer, a secondary frequency standard, a device for rapid determination of unknown frequencies or simply a multi-purpose general laboratory instrument.

AUTOMATIC: This unit will count for a precise one second interval, display the results in direct reading form for a period variable from one to five seconds, and then automatically recycle. On "Manual" operation the instrument will count for one second and display the result indefinitely until the "reset-count" button is again depressed.

MODIFICATIONS: Standard modifications available: a selectable 0.1, 1, and 10 second time base; addition of mechanical register for extended range; addition of panel switch to permit use as straight counter; scanning feature to provide a time base in any multiple of 10 seconds. Special modification including accessories such as tachometer pickups and photocell arrangements can be supplied to meet specific requirements.



TIM* for

- TIME INTERVAL MEASUREMENTS
- PRECISE LOW-FREQUENCY MEASUREMENTS
- HIGH SPEED COUNTING

THE BERKELEY TIME INTERVAL METER*, Model 510, provides a direct reading of elapsed time between any two events in the range of 0.000010 to 1.0000 seconds. Accuracy of measurement is ± 10 u/secs. Any occurrences that can be translated into changing voltages may be timed. Timing may be started and stopped by independent voltages. The polarity of these control voltages may be selected by means of toggle switches so that the unit may be started and stopped by either positive or negative pulses. A sensitivity control permits selection of the amplitude of the start or stop voltages at optimum level for elimination of interference.

OPERATION: By use of photocell attachments the interval between two separate light flashes may be timed. Similarly by use of an added photochannel and a single photocell duration of a light period or a dark period may be determined.

MODIFICATIONS: Standard modifications available: addition of a photocell channel; the addition of a mechanical register to extend range to 10 seconds; threshhold control to permit selection of precise amplitude of input pulse so unit may be made to operate at any desired position on sine wave; panel switch to permit use as straight counter.

DIRECT READING: The only truly direct reading equipment of its kind, presenting results in decimal form on an illuminated panel. No interpolation, no lights to add. A convenience in the laboratory; a necessity in production.

COMPACT: The Models 554 and 510 are standard 19″ single rack units mounted in Berkeley cabinets 20¾″ wide x 10½″ high x 15″ deep. Weight per unit, approximately 60 pounds.

For complete information, write for Data Sheets IRE-510 and IRE-554

Berkeley Scientific Corporation
2200 WRIGHT AVE. • RICHMOND, CALIF.

A NATIONAL ORGANIZATION

Berkeley Scientific Representatives: DALLAS, TEX. — John A. Green Co. • VANCOUVER, B. C. — Hugh M. Birch-Jones Co. • CLEVELAND — J. R. Dannemiller • MONTREAL, QUEBEC — Electrodesign • CHICAGO-KANSAS CITY — Everett Associates • NEW YORK CITY (Export) — Frathom Co. • NEWARK - WASHINGTON, D. C. - PHILADELPHIA — Gawler-Knoop Co. • MINNEAPOLIS, MINN. — Graybar Electric PORTLAND, OREGON — Hawthorne Electronics • DENVER - SALT LAKE CITY — Mine & Smelter Supply ATLANTA — Murphy & Cota • ROCHESTER, N. Y. — E. A. Ossman • LOS ANGELES — V. T. Rupp Co. DETROIT — S. Sterling Co.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 87A)

Preamplifier-Equalizers

Brociner Electronics Laboratory, 1546 Second Ave., New York 28, N. Y., is marketing new preamplifiers which are improved versions of the Model A65 unit that is claimed to produce maximum quality obtainable from phonograph records.

They are mechanically very similar to the older unit and include the following new features: additional turnover step for exact low-frequency equalization of LP records; increased gain—90 times (39 db voltage gain)—permits use of new low-output dynamic pickups; lower output impedance, 20,000 ohms, allows use of longer cable for output without loss of highs; three-stage amplifier.

(Continued on page 90A)

SECON

Nickel alloy, filament wire and ribbon: flat—grooved—crowned.

Grid wire electroplated.

Alloys for special requirements.

Pamphlet PR sent upon request.

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AVIATION DYNAMOTOR
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INPUT VOLTS
28 DC
OUTPUT VOLTS
230 DC
INPUT AMPS
1.6
OUTPUT AMPS
.100
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DUTY
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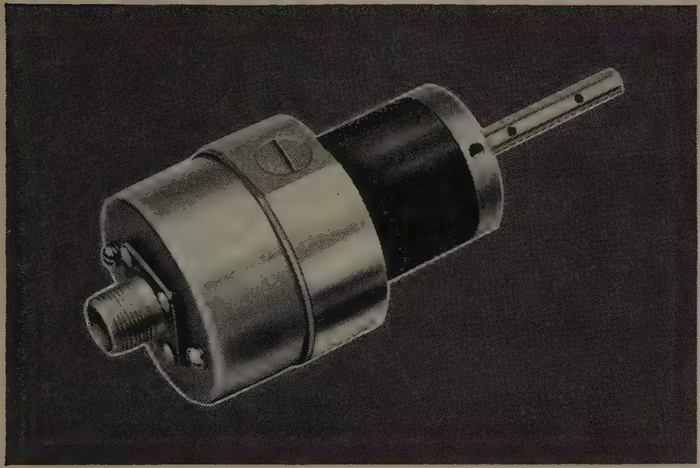

WITH SPECIALIZED DYNAMOTORS AND DC MOTORS

When you are faced with specifications that place impossible requirements on dynamotors or small DC motors, according to World War II standards, take advantage of recently developed improvements in high temperature and high altitude techniques by simply outlining your requirements to Bendix. Model units *exactly* meeting your performance specifications will be developed and tested for pre-production use—production units will then follow in accordance with your manufacturing schedule.

DYNAMOTORS
Regular • Multiple output • Special purpose
DC MOTORS
1/100 hp—1/2 hp • Continuous and Intermittent Duty
DC Servos and special motors

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RED BANK DIVISION

Write for this colorful and informative book—it's free. You'll find it loaded with facts and figures about all types of dynamotors.

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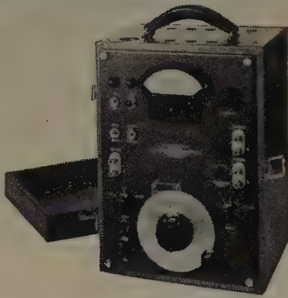
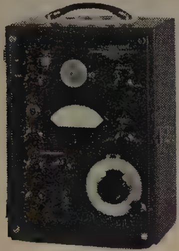
AVIATION CORPORATION

INSTRUMENTS THAT BELONG IN *Your* LABORATORY

Type 310-A Z-Angle Meter — 30 to 20,000 c.p.s.

Measures impedance directly in polar co-ordinates as an *impedance* magnitude in ohms and *phase angle* in degrees Z/± Θ. Measures, with equal ease, pure resistance, inductance, capacitance or complex impedances comprised of most any RLC combinations. Range: Impedance (Z), 0.5 to 100,000 ohms; Phase Angle (Θ), +90° (XL) through 0° (R) to —90° (Xc). Accuracy: Within ± 1% for impedance and ± 2° for phase angle. **Price: $470.00.**



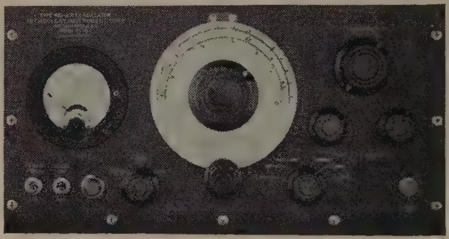


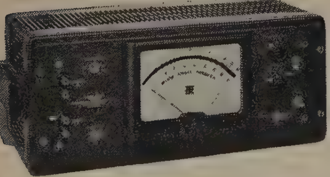
Type 311-A R-F Z-Angle Meter for radio frequencies — 100 kc to 2 mc.

Simplifies laboratory and field *impedance* and *phase angle* measurements. Ideal for checking impedance of coils, transformers, coupling networks, lines, filters, antennas, etc. Direct-reading Impedance Range: 10 to 5,000 ohms up to 200 kc, and 10 to 1,000 ohms at 1 mc. Phase Angle: +90° (XL) through 0° (R) to —90° (Xc). Accuracy: Impedance to within ± 3%, and phase angle ± 4°. **Price: $385.00.**

Type 410-A R-F Oscillator — 100 kc to 10 mc. (Special models 46.5 kc to 4.65 mc available.)

Power oscillator for use as bridge driver and general laboratory measurements. Features: High stability, high output (approximate 30 volts), 50-60 Ω output impedance, expanded frequency scale, direct reading output voltmeter, compact design. **Price: $385.00.**





Type 320-A Phase Meter — frequency range 20 cycles to 100 kc.

The *first* commercially available all-electronic instrument that directly measures the phase angle between two voltages *in a simple* operation. Ideally suited to applications in such fields as audio facilities, ultrasonics, servomechanisms, geophysics, vibrations, acoustics and many others.

Phase angle readings made directly without balancing . . . stable at frequencies as low as 2 to 3 cycles. Voltage range: 1 to 170 peak volts. Terminals for recorder . . . choice of relay-rack or cabinet mounting. **Price: $525.00. Cabinet: $25.00.**

Type 500-A Wide Band Decade Amplifier

Designed for use with the phase meter at voltage levels below one volt and as a general purpose laboratory amplifier—features high gain negligible phase shift and wide band width. Unique circuitry—which employs three cathode followers—offers wider frequency range, higher input impedance and lower output impedance than other types. Panel switch selects proper feedback compensation when either optimum amplification or phase shift operation is desired.

Outstanding specifications: *Amplification*—10; 100; 1000 selected by rotary switch . . . *Accuracy*—±2% nominal . . . *Frequency response*—±0.5db from 5 cycles to 2mc on gain of 10; ±0.5db on 5 cycles to 1.5mc on gain of 100; ±0.8db from 5 cycles to 1mc on gain of 1000 . . . *Phase shift*—0±2° from 20 cycles through 100kc . . . *Gain stability*—constant with line voltages (105-125v).

Prices: Single Type 500-A in cabinet, $205.00 (Rack mount, $200.00): Dual Type 500-AR in cabinet, $425.00.

Technical catalog—yours for the asking. Contains detailed information on all TIC Instruments, Potentiometers and other equipment. Get your copy without obligation—write today.

TECHNOLOGY INSTRUMENT CORP.
531 Main Street, Acton, Massachusetts
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Manhasset, N.Y.-Manhasset 7-3424 Dayton, Ohio-Michigan-8721 Dallas, Texas-DIxon 9918

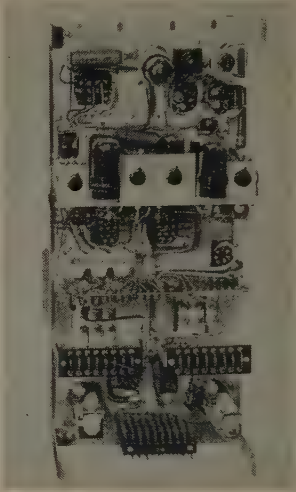
News New—Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 88A)

Medium-Haul Carrier Telephone System

To meet the need of organization requiring a greater number of telephone channels over moderately long lines, **Federal Telephone and Radio Corp.**, 100 Kingsland Rd., Clifton, N. J., has developed a medium-haul carrier telephone system known as the FTR 9-H-2. This system which is stackable to three channels will operate on open telephone wire over distances ranging up to 225 miles.



The 9-H-2 carrier system employs single-sideband transmission and operates at frequencies that are co-ordinated with those of other carrier telephone systems. The signal receiving circuit of the 9-H-2 system has been specially designed to make it less sensitive to pulse ratio variations, and a new pulse ratio adjustment has been incorporated to permit optimum pulsing.

Because of its compact design each of the 3-channel terminals of the new system can be installed in only 8¾ inches of rack space or 26¼ inches for a 3-channel system. Another feature is the hermetic sealing of all magnetic components that might be adversely affected by moisture.

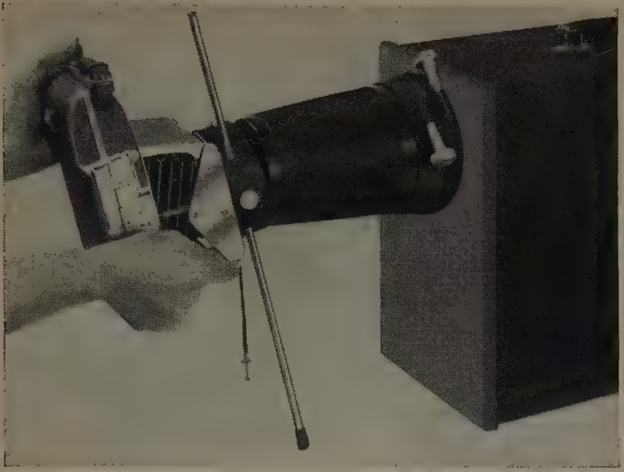
The 9-H-2 channels are also suitable for the operation of multichannel voice frequency carrier telegraph systems operating in the 300- to 2,700-cps range. And of speech-plus-duplex telegraphy on either a two- or four-wire basis.

Remote Mixer—Preamplifier

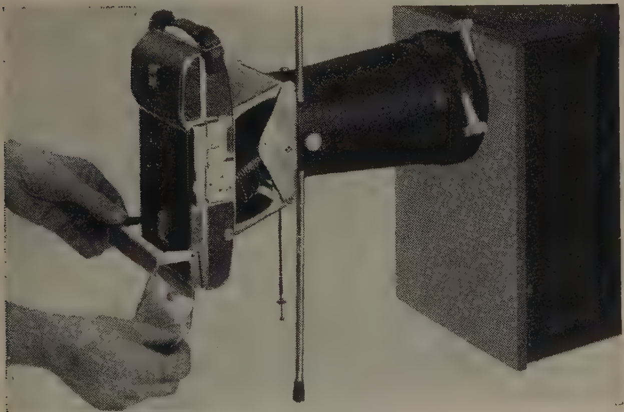
Rauland-Borg Corp., 3515 Addison St., Chicago 18, Ill. introduces a new completely self-contained remote mixer and preamplifier. It is designed to mix four inputs (high or low impedance mikes and crystal pickups) and to feed the program over remote line to main amplifying equipment located at any required distance away (up to several miles, if desired). The Model 1904 Mixer-Preamp may be instantly converted for use with from one to four low-impedance mikes by inserting Rauland R1002 plug-in transformers. Other

(Continued on page 92A)

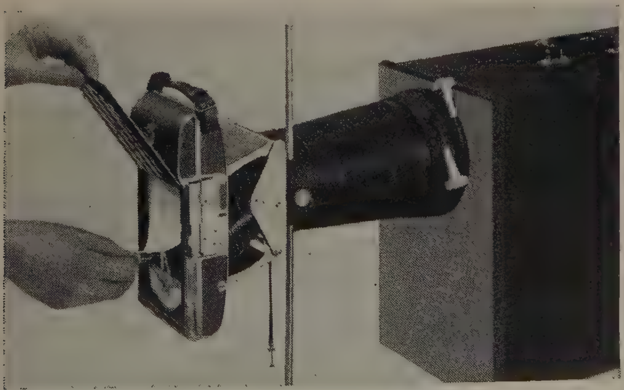
How to make Oscillograms *FAST!*



Set up the camera. The Fairchild-Polaroid camera consists of three units: adapter ring, hood, and camera body. To set it up, you place the handy adapter ring over the oscilloscope bezel, slip the hood into the ring, then snap the camera into the bayonet lock on the hood. That supporting rod is a safety feature that protects both camera and oscilloscope.



Pull the tab to finish exposed print. After a snap of the shutter, the exposure is made and you're ready to finish the print. If you want two exposures, it's easy to move the camera body down and make a second exposure. To finish the print, you merely pull tab at back of camera.



Remove the finished print. A minute after you've pulled the tab, the finished print is ready for evaluation. Just open the camera back and there it is. An easy job, but you have a photographically accurate record of the trace in less time than you could sketch it from memory.

—SET UP THE CAMERA
—SNAP THE SHUTTER
—SEE THE PRINT

ALL IN 3 MINUTES—or even less
with the Fairchild-Polaroid® Oscilloscope Camera

The easiest way is the fastest way when you're photographing oscilloscope images with the Fairchild-Polaroid® Oscilloscope Camera.

No more darkroom processing! With this new camera it takes only two minutes (less if you're fast) to set up and snap the picture, one minute to finish a print. Each 3¼ x 4¼ print records traces exactly one-half life size to make comparisons easy.

Write for complete data and prices on F-284 Oscilloscope Camera Kit including camera, carrying case, and film. *Fairchild Camera and Instrument Corporation, 88-06 Van Wyck Boulevard, Jamaica 1, N. Y.* Dept. 120-14C1.

SPECIFICATIONS

LENS—Special 75 mm. f/2.8 Wollensak Oscillo-anastigmat.

SHUTTER—Wollensak Alphax; speeds 1/25 sec. to 1/100 sec., "time," and "bulb."

FOCUS—Fixed (approx. 8 in.)

PICTURE SIZE—3¼ x 4¼ in. (2 or more images per print; 16 exposures per roll of film.)

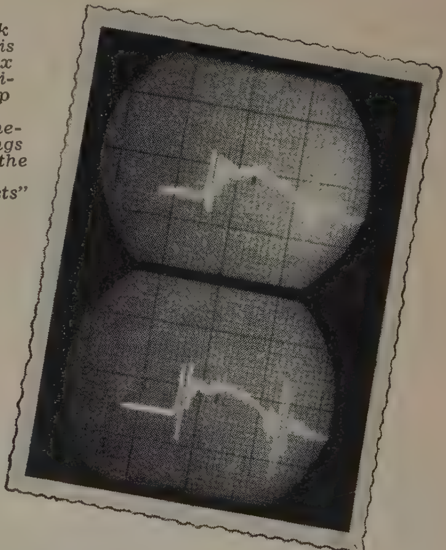
IMAGE SIZE—One-half reduction of scope image.

WRITING SPEED—to 1 in/μsec at only 3000V accelerating potential; higher speeds at higher voltages.

DIMENSIONS—Camera, 10½ x 5¼ x 6¼ in.; hood, 11 in. length, 7½ in. dia.; adapter, 2 in. width, 6⅝ in. max. dia.

WEIGHT—Complete, 7¾ lb.

Typical of the work being done with this camera is this 3¼ x 4¼ print of 35-millisecond single-sweep transient—one of a series of accelerometer-output recordings that made possible the completion of nine recorded "drop-tests" in 40 minutes.



FAIRCHILD
OSCILLOSCOPE RECORDING CAMERAS

for Uninterrupted Communications across OCEANS and CONTINENTS...

dependable
ANDREW Rhombic Antenna Equipment

Whether your problem is uninterrupted communication halfway around the world . . . or only 100 miles . . . ANDREW offers you (1) a world-wide reputation of reliability and (2) the convenience of obtaining all necessary equipment from one dependable source.

- **Receiver Coupling Unit** efficiently distributes the output of one antenna among as many as 10 receivers. Interaction between receivers is held to negligible levels. Power gain is approximately unity (0 db) over the entire range of operation. A 4-channel unit is also available.
- **Rhombic Receiving Antenna Kit** contains in one "package" everything you need for an antenna except poles.
- **Transmitting antennas** available on special order.
- **Rhombic Antenna Coupling Transformer** is a broad band, low loss unit which matches the balanced impedance of the rhombic to the unbalanced impedance of a coaxial line.
- **Transmitting Rhombic Tuning Units** for single or multiple frequencies are available on special order.

For Rapid, Frequent Changes in COAXIAL CIRCUITS...

- (a) **Coaxial Patch Panel** has 24 jacks. Fits 19" relay rack. Facilitates switching coaxial circuits.
- (b) **ANDREW Coaxial Jacks and Plugs** are simple to install. No soldering through a window. Just remove one screw, slide the sections apart and solder.

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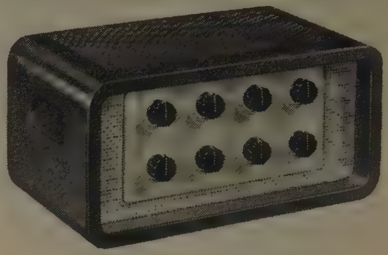
WORLD'S LARGEST ANTENNA EQUIPMENT SPECIALISTS
TRANSMISSION LINES FOR AM-FM-TV · ANTENNAS · DIRECTIONAL ANTENNA EQUIPMENT
ANTENNA TUNING UNITS · TOWER LIGHTING EQUIPMENT

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 90A)

features include: master gain control, separate bass and treble controls, self-contained 24-volt ac supply and switch for remote relay control of main amplifying equipment.



Specifications: Output: measured at 100, 400 and 5,000 cps—300 mw, 2 per cent at 600 ohms. Gain: microphones—109 db (2 Mc), 96 db (100,000 ohms), 96 db (150 ohm input); phono—73 db ($\frac{1}{2}$ Meg. input). Master control—15 db. Frequency response: ±1 db, 40 to 20,000 cps. Output impedance—150/600 ohms. Hum and noise level: 47 db below rated output (unweighted) on mike, 60 db below rated power output (unweighted) on phono.

(Continued on page 94A)

- Special Attention Given to Prototypes
- Development of Special Devices
- Contract Manufacturing of:

Aircraft Antennas
Projection Equipment
Magnetic Recording
Audio, Video, and other
Electronic Assemblies

Inquiries given special attention.
Write for full details our facilities.

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HOPE THIS DOESN'T WAKE THE BABY!

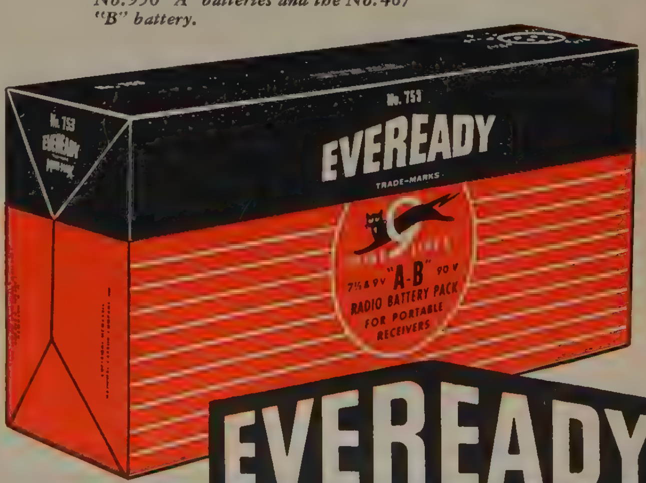
You *can* use a cannon cracker to make it fit...

BUT it's simpler to design the radio around the battery!

● The proper starting point in designing a portable radio is the batteries. Obviously, the efficient way is to pick good, reliable, long-lasting batteries and design the set around them. "Eveready" brand radio batteries are A-1 on all counts. The complete line includes batteries for virtually any set you may be planning. 'Eveready" batteries are available everywhere. Users prefer sets with "Eveready" batteries which are easy to replace.

CONSULT OUR BATTERY ENGINEERING DEPARTMENT FOR COMPLETE DATA ON "EVEREADY" BATTERIES.

The No. 753 "Eveready" "A-B" battery pack provides plenty of power for compact, pick-up portables. For smaller portables, we recommend "Eveready" No. 950 "A" batteries and the No. 467 "B" battery.



EVEREADY
TRADE-MARK
RADIO BATTERIES

"Eveready", "Mini-Max", "Nine Lives" and the Cat Symbol are trade-marks of

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Try Remler for Service-Tested "Hard-to-Get" Components

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TYPE 56
octal socket

Custom Components

Metal-plastic components designed and manufactured to order. Write for quotations specifying electrical and mechanical characteristics. Describe application. No obligation.

REMLER TUBE SOCKETS

● STANDARD FOR 30 YEARS... THE BEST IN THE INDUSTRY

Heavy duty phenolic sockets with high current wiping action contacts . . . for industrial, transmitter and test applications. Rugged. Years of tube insertions and withdrawals do not impair contact effectiveness. Black phenolic is standard, low loss phenolic or alkyd on order.

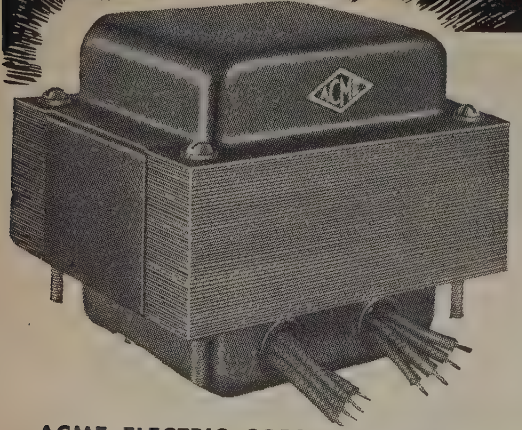
Remler Company Ltd. 2101 Bryant St. San Francisco 10, Calif.

Remler

Since 1918 PIONEERS IN ELECTRONICS AND PLASTICS

FOR BETTER PERFORMANCE BETTER BUY

Acme Electric TRANSFORMERS



You write the specifications and Acme engineers will design a transformer with the exact output characteristics to provide "top" performance for your product. And remember, in addition to quality performance, Acme also can provide quality production in custom designed electronic transformers.

ACME ELECTRIC CORPORATION • 445 Water St., Cuba, N.Y., U.S.A.

Acme Electric TRANSFORMERS

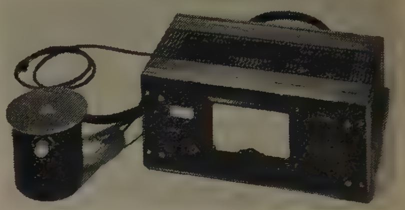
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 92A)

New Electrometer

The Model 361-20 dynamic condenser electrometer, designed for general laboratory measurement of small dc currents and voltages in high resistance circuits, is now available from the manufacturer **Loudon Instruments, Inc.**, 5644 Lake Park Ave., Chicago 37, Ill.



Typical applications are: ionization chamber measurements of radiation, mass spectrographs, biological potentials, chemical titrations, and insulator and capacitor leakage measurements.

Special features are stability of calibration and high response speed. Zero drift in the amplifier is eliminated by use of dynamic condenser which converts the dc input to an ac signal. High amplifier gain and high feedback ratio make calibration independent of component changes and supply voltage variations.

Voltage ranges are 0–10, 0–100, and 0–1000, mv with range selector switch. Multiple input resistors (10^9, 10^{10}, and 10^{11} ohms standard, others available) with selective switching and grounding key are built into the head. Provision is made for current, voltage, and rate of charge measurement. Terminals are provided for the connection of standard recorders. The sealed head unit containing the input circuits and preamplifier can be located at the amplifier or remotely. A removable top plate provides for mounting of ionization chambers. The dynamic condenser is located in a separate hermetic sealed inner shield. All high impedance surfaces, including the dynamic condenser plates, are gold-plated to minimize contact potential problems.

Accessories are available for complete measuring systems, such as ionization chambers, input switches, and recorders.

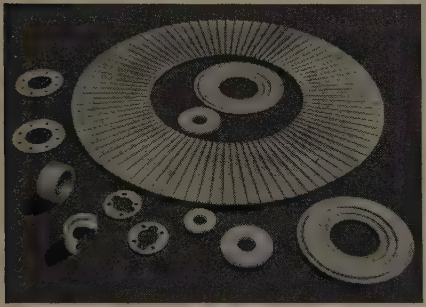
Minimum-Adjustment FM Communications Monitor

A new, low-cost FM communications monitor that requires no adjustment during operation was announced this month by **Hewlett-Packard Co.**, 395 Page Mill Rd., Palo Alto, Calif.

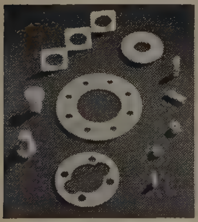
(Continued on page 96A)

TEFLON

has outstanding insulating properties



Power factor, less than 0.0005; dielectric constant, only 2.0—over entire frequency measured to date. Excellent dielectric and mechanical strength; zero water absorption. Serviceable in the temperature range -90°F. to 500°F. Tough, resilient, unaffected by outdoor weathering, and completely chemical-proof.



Teflon is ideal for high-voltage, high-temperature, high- or ultra-high-frequency service in TV transmitters, radio, radar and other electrical equipment. We supply Teflon spacers for coaxial cables, Teflon inserts for coaxial connectors, *all types of molded and/or machined Teflon parts.*

Teflon Stock and Fabricated Parts

Sheets
Cylinders
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A complete line of Teflon stock—experimental or production quantities. Also, variations of stock shapes and sizes or special molded or machined parts exactly to specifications. We are the country's leading manufacturer of Teflon products.

Teflon Products Division

UNITED STATES GASKET COMPANY
611 N. 10th St.
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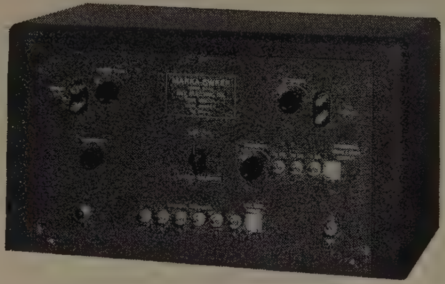
KAY

A Video Sweeping Oscillator With Frequency Marks

NEW



NEW

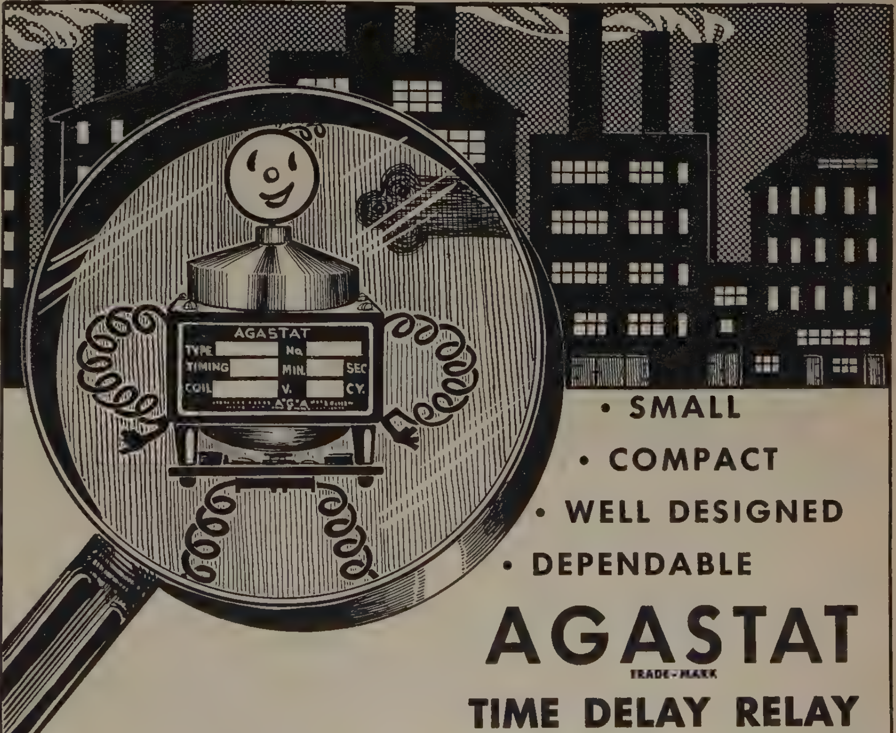
THE MARKA-SWEEP MODEL VIDEO

The Marka-Sweep Model Video is an electronically swept video sweep oscillator covering frequencies up to 20 mc. Crystal positioned marks of pip type are provided at 1, 2, 5, 10, 15 and 20 mc. By use of external signal generator a variable frequency pip type marker is available. Output maximum is 0.3 volt from a 72 ohm internal impedance.

- Sweep Ranges: 50 kc to 10 mc and 50 kc to 20 mc.
- Crystal positioned pip type MARKS connected directly to oscilloscope.
- Separate attenuators on pip markers and video output.
- Sawtooth sweep for sweeping video output and deflecting oscilloscope horizontal.
- Produces Zero Level Baseline on oscilloscope.
- Price: $495.00 F.O.B. Factory.

KAY

KAY ELECTRIC COMPANY
14 Maple Avenue
Pine Brook, New Jersey
Phone CAldwell 6-4000



- SMALL
- COMPACT
- WELL DESIGNED
- DEPENDABLE

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TIME DELAY RELAY PROTECTS BIG INDUSTRY PROCESSES

A·G·A AIRPORT LIGHTING
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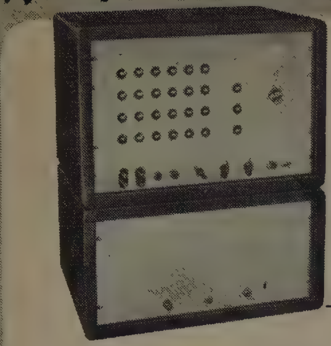
Address inquiries to Special Products Division

American Gas Accumulator Company
1027 Newark Avenue, Elizabeth 3, New Jersey



NEW! FREQUENCY AND TIME MEASUREMENTS ACCURATELY . . . CONVENIENTLY!

-using $f=\frac{n}{t}$

ANY FACTOR MAY BE MEASURED FOR FIXED VALUE OF THE OTHER

Universal 6-in-One
MEGACYCLE FREQUENCY-TIME COUNTER

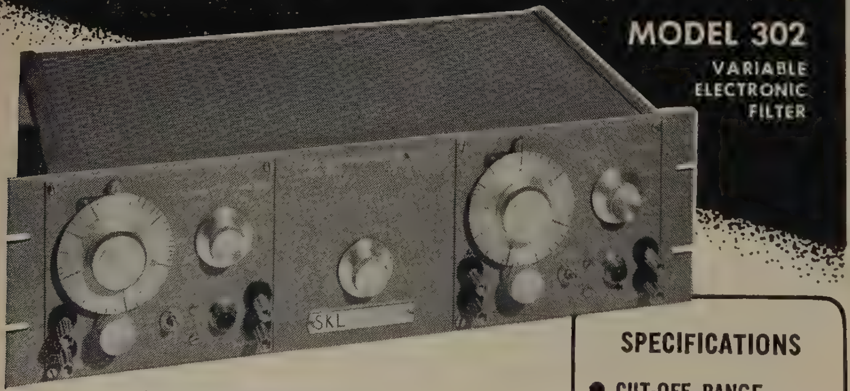
Model 801
by Potter

Now, the Potter Instrument Company offers all in one equipment, the features heretofore available only in separate counting systems. Two complete counting channels, a 100 kc crystal oscillator time base and unique gating circuits are combined to provide the new FREQUENCY-TIME COUNTER.

FREQUENCY MEASUREMENTS	0 to 1 mc range by counting cycles per pre-selected time or by measuring time per pre-selected count. Accuracy 0.001% minimum.
TIME INTERVAL MEASUREMENTS	0 to 10 seconds ± 10 microseconds.
FREQUENCY RATIO MEASUREMENTS	Ratio of two external frequencies can be measured.
SECONDARY FREQUENCY	100 kc crystal oscillator with divided frequencies available at 10, 1 kc and 100, 10, 1 cps.
TOTALIZING COUNTER	Six decades, pulses 0 to 1 mc, sine wave 10 cps to 1 mc.
DIRECT RPM READING TACHOMETER	Through the use of an external 60 count per revolution photoelectric disc generator an accuracy of ± 1 rpm is obtained.

Please address inquiries to Dept. 5-J

POTTER INSTRUMENT COMPANY
INCORPORATED
115 CUTTER MILL RD., GREAT NECK, NEW YORK



CONTINUOUSLY
VARIABLE FILTERS

MODEL 302
VARIABLE ELECTRONIC FILTER

"Another SKL first"

The—SKL—Model 302 includes two independent filter sections, each having a continuously variable cut-off range of 20 cps to 200 KC. Providing a choice of filter types each section has 18 db per octave attenuation. When cascaded 36 db is obtained in the high and low pass setting and 18 db in the band pass position. With low noise level and 0 insertion loss this versatile filter can be used as an analyzer in industry and the research laboratory or to control sound in the communications laboratory, radio broadcasting, recording and moving picture industries.

SPECIFICATIONS

- CUT-OFF RANGE 20 cps to 200 KC
- SECTIONS 2—can be high, low and band pass
- ATTENUATIONS 36 db/octave maximum
- INSERTION LOSS . 0 db
- NOISE LEVEL 70 db below 1 volt
- FREQUENCY RESPONSE 2 cps to 2 MC

SKL SPENCER-KENNEDY LABORATORIES, INC.
181 MASSACHUSETTS AVE., CAMBRIDGE 39, MASS.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 94A)

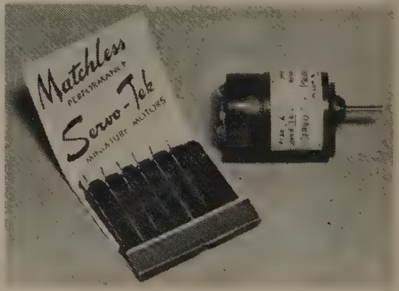
Designated -hp- Model 337A-B FM communications monitor, the new equipment is designed for use by nontechnical personnel. It provides FM emergency and communications networks with a monitor equalling in performance and operation of much more expensive equipment used by commercial FM broadcasters. The new unit uses the same pulse-counter circuits employed in the company's monitor for commercial broadcasters. This eliminates troublesome tuning of discriminators and does away with frequent adjustment of voltage levels. No IF calibration is required because the IF is low (30 kc) and circuits are not sensitive to signal level changes.

The monitor gives continuous indication of frequency and modulation swing, and monitors by transmitter output sampling or antenna pickup. It includes a peak modulation indicator and an audio output for aural monitoring. Frequencies from 30 to 175 Mc may be monitored, and the instrument is sensitive enough to pick up mobile units some distance away.

The unit is available as Model 337A, operating on one crystal-controlled frequency, or Model 337B, operating on any of four frequencies.

Miniature PM Field-Type DC Motor

Servo-Tek Products Co., 4 Godwin Ave., Paterson, N. J., has recently begun production of a line of miniature permanent magnet field type dc motors. These units are 1⅛ inches in diameter by 1½ inches long and weigh approximately 2½ ounces. Motor voltage ratings from 6 to 28 volts are available for varied service applications ranging from fan or blower uses to telemetering sequence switch drives. Front flange or base mounting types are available.



These motors employ many features not formerly available in precision miniature motors of this general type. A cylindrical, or ring type, Alnico V field magnet is used in conjunction with a 14-commutator segment armature. Long brush life and excellent commutation characteristics are achieved, according to the manufacturer.

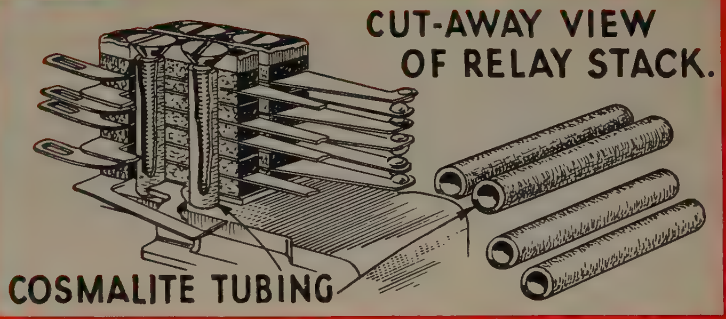
All units employ precision ball bearings and are available with high altitude brushes for aircraft and allied services. Full information and application engineering are available from the manufacturer at your request.

(Continued on page 98A)

ALLIED CONTROL RELAYS
built with
Cleveland PHENOLIC TUBES

ensure

- ★ DEPENDABILITY
- ★ PRECISION PERFORMANCE
- ★ LONG LIFE
- ★ ECONOMY



The Allied Control Co. has built a long and enviable record as a quality supplier of control relays to both private industry and governmental services.

Their S K Relay shown above, is typical of the various Allied Relays in which CLEVELAND CONTAINER tubing provides excellent service.

It is likewise the answer for hundreds of other problems of manufacturers in the electrical industry.

Write today for our new descriptive brochure. Also ask for quotations and samples to meet your exact specifications.

CLEVELITE* and COSMALITE*
Laminated Phenolic Tubing

combines electrical and physical properties to meet the most exacting requirements.

CLEVELITE is produced in six grades . . .
COSMALITE in four grades . . .
A grade for EVERY need.

Cleveland Container's large production facilities further ensure minimum production costs as well as dependable deliveries.

Why pay more? . . . for the BEST call CLEVELAND.

* Trade Marks

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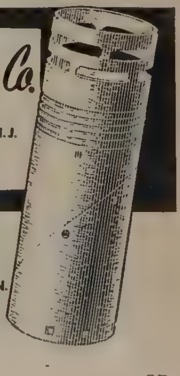
ABRASIVE DIVISION at Cleveland, Ohio
CANADIAN PLANT: The Cleveland Container, Canada, Ltd., Prescott, Ontario



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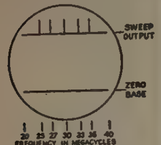
NEW ENGLAND	R. S. PETTIGREW & CO., 10 N. MAIN ST., WEST HARTFORD, CONN.
CHICAGO AREA	PLASTIC TUBING SALES, 5215 N. RAVENSWOOD AVE., CHICAGO

KAY

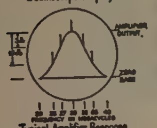
A Wide Band Sweep With Markers For Aligning Radar IF Amplifiers. Displays Amplitude vs. Frequency Response on Standard Oscilloscope

Oscilloscope Display



Detected Rada-Sweep Output

Oscilloscope Display



Typical Amplifier Response

THE RADA-SWEEP • NEW

FEATURES:

- **Increases Production Speed** when substituted for conventional CW point-by-point methods
- **Wide Band** Linear Sweep
- **Pulse Type** Crystal Positioned Marks at Specified Frequencies
- **Marks Individually** Switched On or Off
- **Output Amplitude** Remains Virtually Constant While Sweeping
- **Output Level** Control on IF and Pulse Outputs

Designed specifically for producing a constant amplitude frequency modulated signal for exploring the frequency response of Radar IF amplifiers. Frequency marks of pulse type are connected directly to oscilloscope and are not affected by IF amplifier under test. These marks are controlled by front panel switches which turn them on or off individually. Marks at any specified frequency can be supplied and frequency is changed by changing plug-in crystals. A wide or a narrow sweep may be selected by front panel switch.

Price: $395.00 F.O.B. Factory with marks as above. Special marks at $20.00 each. Prices 10% higher outside U.S.A. and Canada.

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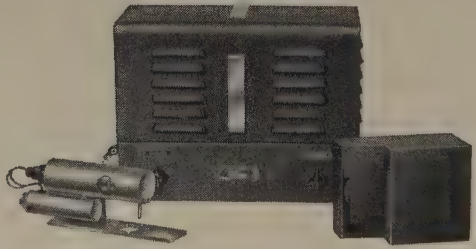
Phone CAldwell 6-4000

At Last...

SENSITIVE AND RELIABLE POWER MEASUREMENTS IN THE MM WAVE REGION WITH THE

GOLAY Pneumatic Detector



In the frontier spectral region where radio meets infra-red, and where you can generate coherent radiation, but lack sufficient power for its electrical detection, your problem can be solved with a Golay Pneumatic Infra-red and Millimeter Waves Detector. Among the characteristics that render the Golay Detector useful for this and other purposes are:

1. Sensitivity of 6×10^{-11} watts Root Mean Square Equivalent Noise Input when used with the "chopped radiation" method and with a recording time constant of 1.6 second.
2. Uniform sensitivity in the entire spectrum from the ultra-violet through the visible, the infra-red, and up to and including the millimeter waves region — subject only to window limitations.
3. Linear response up to 1 microwatt input.
4. When greater sensitivities are desired, the use of an R-C filter with a ½ min. time constant will yield a RMSENI of 1×10^{-11} watt.

Write for Bulletin No. 10, or state your specific problem.

THE EPPLEY LABORATORY, INC.
NEWPORT, RHODE ISLAND, U.S.A.

SCIENTIFIC INSTRUMENTS

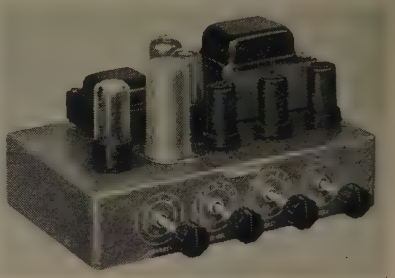
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 96A)

High-Fidelity Amplifier

A new low-cost amplifier has been added to the **Rauland-Borg Corp.,** 3523 Addison St., Chicago 18, Ill., high-fidelity line. Known as the Model 1810, the new unit is primarily designed for record reproduction in custom installations. The amplifier is rated at 10 watts output, and is equipped with a 3-position input selector switch for magnetic or crystal pickup and high level for auxiliary input.



Specifications: Output—measured at 100, 400, and 5,000 cps—10 watts at 3 per cent harmonic distortion. Percentage intermodulation distortion taken at 60 and 7,000 cps with 4 to 1 ratio—2 watts 1.5 per cent (home level), 5 watts 3 per cent, 10 watts 5 per cent. Gain: magnetic pickup—103 db (10,000 ohms); crystal pickup (aux.) input—80 db (500,000 ohms), 73 db (100,000 ohms). Frequency response: ±1 db, 40 to 20,000 cps.

Double-Function Arc-Lamp Power Supply

Either direct-current or single-flash operation of AH-6 or BH-6 mercury-vapor arc lamps can be obtained from 115 volt 60-cps power with the Model 1-BC power supply, a product of **Huggins Laboratories,** 736 Hamilton Ave., Menlo Park, Calif. Direct-current operation provides the steady light required for many research applications, while pulsed operation gives a brilliance about 200 times greater, with a duration of 10 microseconds, approximately. Either mode of operation can be selected from a single switch.

With dc setting, the power supply delivers one kilowatt—1.2 amperes at 800-v. open-circuit voltage of 1,700 volts is supplied for starting the lamp. Standard dc ripple is about 5 per cent, but lower values can be supplied in special units.

With flash operation, the 10-microsecond pulse at a power of approximately 2.5 watt-seconds is provided by a power capacitor discharging through the lamp by means of a thyratron-controlled spark gap. Maximum repetition rate is 6 pulses per minute.

(Continued on page 100A)

for your

Raytheon
Tube
Requirements
in the
Metropolitan
New York Area

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Serving the trade for
over a quarter century

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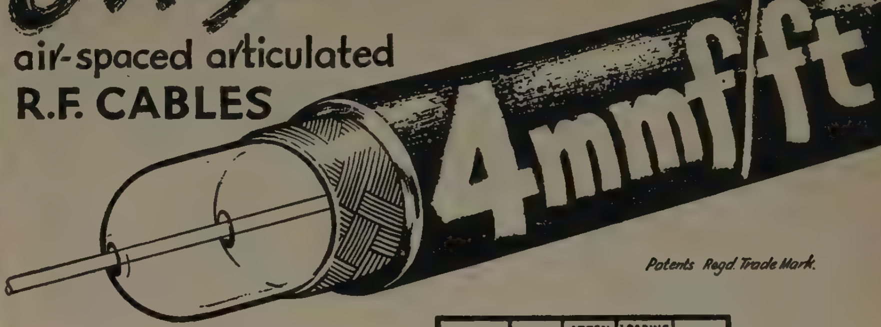
Only *with* **CO-AX**

air-spaced articulated
R.F. CABLES



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CAPACITANCE OR
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SPOT DELIVERIES TO U.S.A
Cable your rush order for shipment by air freight. Settlement by your own $ check

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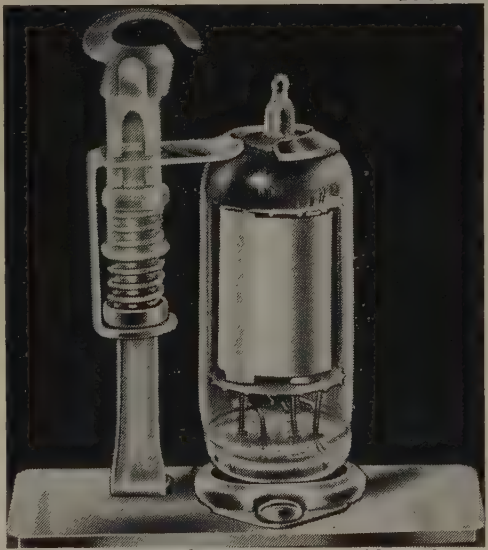
CONTRACTORS TO H.M. GOVERNMENT
138A CROMWELL ROAD · LONDON SW7 ENGLAND
CABLES: TRANSRAD. LONDON.

LOW ATTEN TYPES	IMPED OHMS	ATTEN db100ft of 100 Mc/s.	LOADING Kw of 100 Mc/s.	O.D."	
A 1	74	1.7	0.11	0.36	
A 2	74	1.3	0.24	0.44	
A 34	73	0.6	1.5	0.88	HIGH POWER FLEXIBLE

LOW CAPAC TYPES	CAPAC mmf/ft.	IMPED OHMS	ATTEN db/100ft 100Mc/s.	O.D."	
C 1	7.3	150	2.5	0.36	
PC 1	10.2	132	3.1	0.36	PHOTOCELL CABLE
C 11	6.3	173	3.2	0.36	
C 2	6.3	171	2.15	0.44	
C 22	5.5	184	2.8	0.44	
C 3	5.4	197	1.9	0.64	
C 33	4.8	220	2.4	0.64	V.L.C. ★
C 44	4.1	252	2.1	1.03	

★ *Very Low Capacitance cable.*

New **BIRTCHER TUBE CLAMP**
FOR **MINIATURE TUBES**



POSITIVE PROTECTION AGAINST LATERAL AND VERTICAL SHOCK!

The *New* Birtcher Type 2 Tube Clamp holds miniature tubes in their sockets under the most demanding conditions of vibration, impact and climate. Made of stainless steel and weighing less than ½ ounce, this *New* clamp for miniature tubes is easy to apply, sure in effect. The base is keyed to the chassis by a single machine screw or rivet…saving time in assembly and preventing rotation. There are no separate parts to drop or lose during assembly or during use. Birtcher Tube Clamp Type 2 is all one piece and requires no welding, brazing or soldering at any point.

If you use miniature tubes, protect them against lateral and vertical shock with the Birtcher Tube Clamp (Type 2). Write for sample and literature.

Builder of millions of stainless steel Locking Type Tube Clamps for hundreds of electronic manufacturers.

Builder of Millions of stainless steel locking Type Tube Clamps for hundreds of electronic manufacturers.

The **BIRTCHER** *Corporation*
5087 HUNTINGTON DRIVE • LOS ANGELES 32

VARIABLE MASTER OSCILLATOR
Type 115
Model 1
N

The Variable Oscillator with CRYSTAL STABILITY

High versatility, plus wide range, plus crystal stability and accuracy—that's the unbeatable combination for the best in diversity reception. You get all three with the Northern Radio VARIABLE MASTER OSCILLATOR: The HFO's stability is ± 20 cps/mc for ambient change of ± 25°C.—matching that of any non-temperature controlled crystal. Its range is 2-32 mc continuous. Crystal check points, with 40 curves supplied, permit absolute frequency setting to ± 25 cps/mc. Three crystal-controlled frequencies provide fixed frequency reception. There's a LF crystal oscillator for BFO.

And, this unit also serves as an excellent transmitter exciter and laboratory measuring standard.

See the specifications on this outstanding model in the 1950 IRE Directory. For complete data on the precision-built Northern Radio line, write today for your free latest Catalog P-5.

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143-145 West 22nd Street
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WRITE FOR CATALOG !

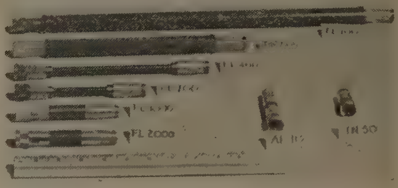
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 98A)

Microwave Test Equipment

A new line of microwave test equipment has been introduced by **Microlab,** 301 S. Ridgewood Rd., South Orange, N. J. The line features low-pass filters, fixed pad attenuators, and low-power terminations.



The low-pass filters are designed to produce a sharp cutoff while minimizing pass-band attenuation. A special design reduces the over-all length of the filters, over previous designs, permitting much lower cutoff frequencies in small units than heretofore available.

The fixed pad attenuators and low-power terminations feature rugged construction and usable frequency range up to 3,000 mc. Type *N* fittings are employed.

(Continued on page 102A)

ZOPHAR
---WAXES
---COMPOUNDS

Anti-Corona high heat-resistant compounds for Fly Back Transformers.

Waxes and compounds from 100° F to 285° F Melting Points for electrical, radio, television, and electronic components of all types.

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Our efficient and experienced laboratory staff is at your service.

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On peacetime boats of commerce and travel—on warcraft—Guardian Relays play major control roles, ranging from Marine radio to navy aircraft. The Series 335 D.C. *approved* Guardian Relay shown above is typical of Guardian units built to rigorous aviation standards. Meets the 10-G Vibration Test and the Mil-R-6106. Generous coil winding area permits single winding up to 15,000 ohms. Parallel and double windings available.

The Series 335 D.C. approved Guardian Relay packs loads of power over a wide operating range, withstands moisture, salt air, temperature changes, dust, vibration and impact. Available in standard open model or with A.N. Connector Plug, Octal Plug and Lug Header hermetic seal containers.

A.N. CONNECTOR PLUG
HERMETIC SEALED
CONTAINER

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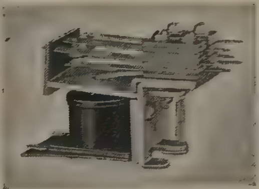
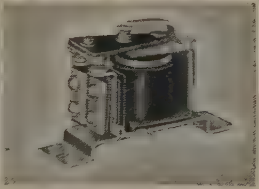
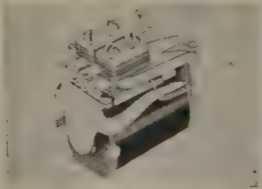
GUARDIAN RELAYS

NEW CATALOG on Hermetically Sealed Guardian Relays with various containers is yours for the asking, cost-free.

Series 30 A.C.


Series 210 A.C.—215 D.C.


Series 220 A.C.


Series 595 D.C.

Series 610 A.C.—615 D.C.

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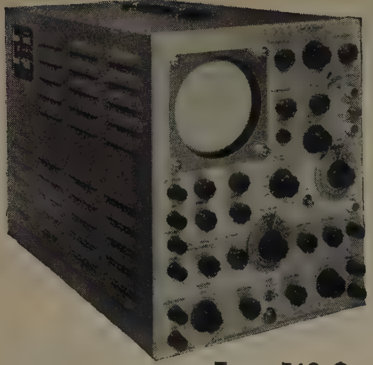
1628-F W. WALNUT STREET CHICAGO 12, ILLINOIS
A COMPLETE LINE OF RELAYS SERVING AMERICAN INDUSTRY

SLOW SWEEPS
HIGH SENSITIVITY



- *Band Pass—DC-2mc*
- *Sensitivity—5mv/cm maximum*
- *Sweeps—.3 sec/cm to 3 µsec/cm*

Type 512 Oscilloscope

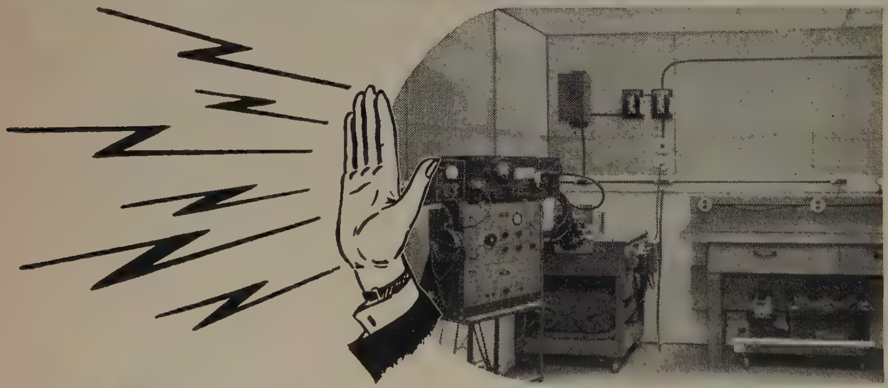
Accurate observation and measurement of slowly recurring phenomena is difficult, if not impossible, by conventional oscilloscopic techniques. The Tektronix Type 512 Cathode Ray Oscilloscope, combining as it does direct-coupled amplifiers, slow sweeps and high accuracy, is recognized by a constantly increasing number of researchers as being an indispensable laboratory tool. New and fruitful approaches to the problems encountered in research are permitted by these features. $950.00 f.o.b. Portland, Oregon.

Write today for detailed specification of Type 512 and other Tektronix instruments.

TEKTRONIX INC.

TEKTRONIX, INC.

712 S.E. Hawthorne Blvd. Portland 14, Ore.



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Reduce the area background level of radio interference to a negligible minimum for critical tests and measurements! Ace Pre-Built Screen Rooms are moderately priced—suppress interference far more efficiently than ordinary screen rooms or enclosures—and provide for a high degree of accuracy by eliminating gross systematic errors in your test setup and calculations. They're easy to install and easy to enlarge or move. Write, wire or 'phone for further details.

ATTENUATIONS of 100 to 140 db.
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News—New Products

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(Continued from page 100A)

Miniature DC Multipole Relays

A complete line of miniature dc relays in 2-, 2-, 2- and 6-pole units with double-throw contacts has been developed by **Struthers-Dunn, Inc.,** 150 N. 13 St., Philadelphia 7, Pa., for reliable service under the extreme operating conditions encountered in modern high-altitude and jet-propelled aircraft and missiles.

Designed to meet USAF Specification MIL-R-5757, the relays are supplied in type A style for operation at ambient temperatures up to 200°C, and type B for use where the ambient temperature is limited to 85°C.

Up to 6-pole double-throw contact arrangements are avilable in hermetically sealed metal containers 1¼ inches in diameter, 1½ inches long and weighing 3 ounces. A rotating solenoid type of magnetic structure and balanced moving parts eliminate contact bounce of false contact operation even under as much as 50 G's shock or 10 G's vibration.

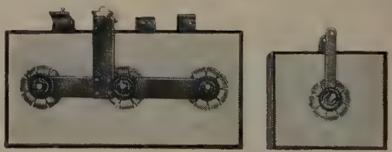
Hermetic sealing makes the relays insensitive to humidity changes and capable of operation at any altitude.

Palladium contacts are nominally rated 2 amperes at 28 volts dc noninductive on permanent installations.

(Continued on page 103A)

SYNTRON

SELENIUM RECTIFIERS



Made by a new process to a uniform, high quality for continuous, heavy-duty service.

1" sq. to 12" x 16" cells—in stacks, or single cells for customer assembly

Write for literature

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242 Lexington
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Use SILVER GRAPHALLOY

For extraordinary electrical performance

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THE SUPREME BRUSH AND CONTACT MATERIAL

for BRUSHES

- for high current density
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- self-lubrication

for CONTACTS

- for low resistance
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Graphalloy is a special silver-impregnated graphite

Accumulated design experience counts — call on us!

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News—New Products

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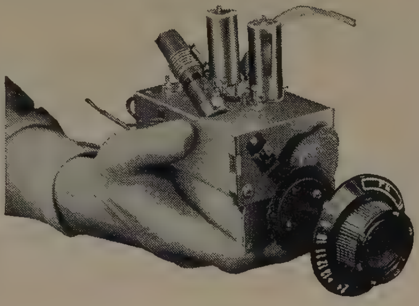
(Continued from page 102A)

Detent-Action Continuous Inputuner

The new Series T3C inputner, announced by the **Electronic Parts Div., Allen B. Du Mont Laboratories, Inc.,** East Paterson, N. J., is a ready replacement, both mechanically and electrically, for the majority of switchtype tuners.



The simplified dial covers all TV and FM channels in only four turns, and occupies the same panel area as indicating devices used on most switch-type tuners. The one-knob operation simply clicks into any TV channel and then fine-tunes for superlative results.

The Series T3C (jobber model, with dial) or Series T3B (manufacturer's model) utilizes the Mallory-Ware 3-gang spiral inductuner plus antenna tuning which provides 4-circuit performance without extending the physical length of the chassis. Dimensions: 4 51/64 inches long, 3 3/32 inches wide, 5 5/64 inches high. Shipping weight, 4 lbs. Available in four models; aligned for sound center IF of 21.25 mc, with or without sound trap. Contact H. Van Rensselaer for details.

Miniature Metal Tubulars

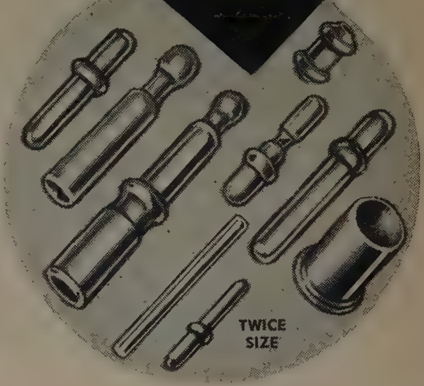
Miniature size Demicon paper capacitors in tubular metal casings for various types of electronic equipment are now available in two types—Dykanol "C" impregnated and high-temperature wax impregnated. Both types are available in six basic styles of case and bracket mountings from **Cornell-Dubilier Electric Corp.,** South Plainfield, N. J.

They are available with inserted tab construction for minimum size and extended foil construction to meet special circuit requirements.

The types are: TWC or TWH unit, with both leads insulated from case; with both leads insulated from case and provided with plastic insulating sleeve; one lead grounded to case with threaded stud mounting; one lead grounded to case; with strap mounting bracket, and with one or both leads insulated from case; and one lead grounded to case with plastic insulating sleeve.

(Continued on page 106A)

Need VOLUME on Small Parts Like These?



Investigate MULTI-SWAGE

Economy Way to Get Volume!

If it's VOLUME you need on small tubular metal parts similar to these, be sure to look into Bead Chain's MULTI-SWAGE Process. Send the part (up to ¼" dia. and to 1½" length) and your specs for a quotation. Chances are you'll find a new way to effect important savings.

Much Cheaper Than Solid Pins

Many prominent users of solid pins for electronic and mechanical purposes have cut costs by switching to Multi-Swaged *tubular* pins . . . without sacrificing strength or accuracy. Often this is possible to accomplish.

Typical Applications —

As terminals, contacts, bearing pins, stop pins, male-female connections, etc., in a wide variety of electronic and mechanical products:—Toys . . . Business Machines . . . Ventilator louvres . . . Radio and Television apparatus . . . Terminal-boards . . . Electric Shavers . . . Phono Pick-ups, etc. *For DATA BULLETIN*, write to

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Manufacturers of BEAD CHAIN — the kinkless chain of a thousand uses, for fishing tackle, novelty, plumbing, electrical, jewelry and industrial products.

You can
NOW BUY
TOWER LIGHTING EQUIPMENT

COMPLETE KITS
EVERYTHING NEEDED
for ANY Tower
150 to 900 Feet
Exposed or Conduit Wired

Don't let lack of some critical fitting hold-up completion of **YOUR JOB!**

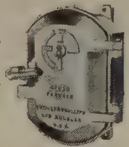
H & P Lighting equipment, consistently specified by outstanding electronic engineers, is furnished as standard equipment by most leading tower manufacturers.

COMPLETE LIGHTING KITS SAVE...
Purchasing Time!
Erection Time!
Completion Time!

300 MM CODE BEACON
Patented ventilator dome circulates the air, assures cooler operation, longer lamp life. Concave base with drainage port at lowest point.

SINGLE and DOUBLE OBSTRUCTION LIGHTS
Designed for standard A-21 traffic signal lamps. Prismatic globes meet CAA specifications.

MERCURY CODE FLASHER
No contact points to wear out. 14-52 flashes per minute.



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Lights automatically, if any part fails.

PROMPT SERVICE and DELIVERY
Order through your jobber or Tower Manufacturer. We will send his name on request.

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PRODUCTION LINE TESTING OF SERVOMECHANISMS

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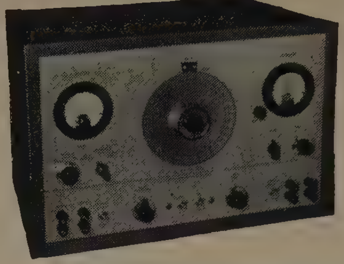

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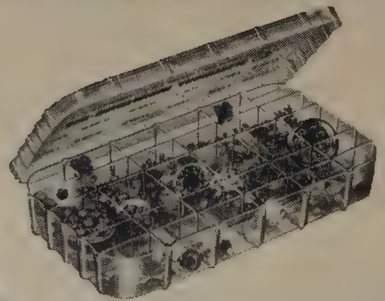
- STANDARD RANGE: .1 TO 20 CYCLES PER SECOND
- SINE WAVE
- SQUARE WAVE
- MODULATED CARRIER 50 TO 800 CYCLES
- READS DIRECTLY SERVO LAG OR LEAD IN DEGREES

E-I HERMETIC SEALING COMPONENTS

ENGINEERS, DESIGNERS, PURCHASING AGENTS! SAVE TIME AND EFFORT

with the **E-I SAMPLE KIT!**



New designers kit contains 81 standard terminals and 11 different headers. These mass produced, economy-priced standard parts solve practically all problems requiring hermetic sealing. Transparent case with labeled bins makes it easy to select the correct component for your needs. The E-I SAMPLE KIT is available at the nominal price of $10.00. Send check with order or request the free E-I illustrated brochure today!

Write for these descriptive bulletins:
849 – Hermetically Sealed Terminals
850 – Hermetically Sealed Multiple Headers
851 – Gasket Type Bushings

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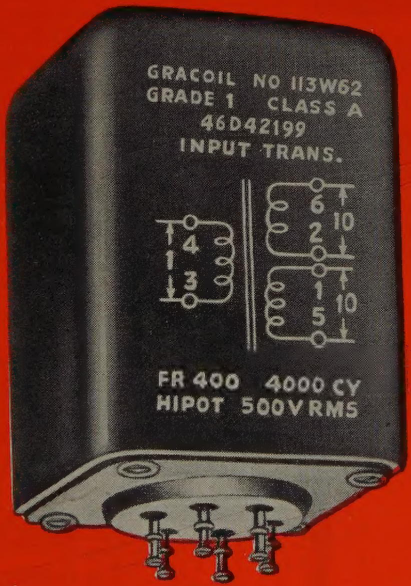
Invitation
TO RECEIVE A
PRODUCTION SAMPLE
Transformer
BUILT TO YOUR SPECIFICATIONS

this is our offer to you . . .

WE WILL, without cost or any obligation whatever, design a PRODUCTION SAMPLE transformer (hermetically sealed to JAN-T-27 or MIL-T-27 Government specifications), or open type construction, if unit is to be used for awarded prime or sub-contract work. Our approach stresses quality of product, efficiency in service and an alertness to techniques that discard the old for more functional methods.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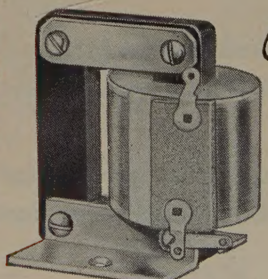

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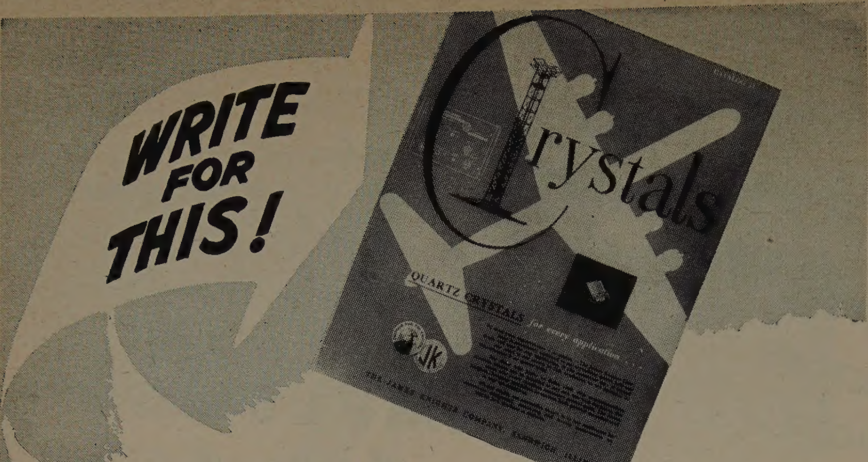
TRANSFORMER
CORPORATION
2734 N. PULASKI ROAD • CHICAGO 39, ILLINOIS


WRITE FOR THIS!
Crystals
QUARTZ CRYSTALS for every application
JK
THE JAMES KNIGHTS COMPANY SANDWICH, ILLINOIS

A new, comprehensive Crystal Catalog by the JAMES KNIGHTS COMPANY is now off the press. It contains the complete JK line, lists modern up-to-the-minute crystals about which engineers will want information in designing their new equipment.

Advances in crystals and holders have been tremendous during the past few years and this JK Crystal Catalog presents for your consideration new crystal types offering greater stability and precision. These new crystals mean improved performance for your new equipment!

In addition to these newer types, JAMES KNIGHTS still offers a complete line of standard crystals for replacement use. You'll find descriptions of all, with dimension drawings, in the new catalog.

WRITE FOR YOUR COPY—TODAY!

JK
CRYSTALS

THE JAMES KNIGHTS CO.
SANDWICH, ILLINOIS

Telesyn **THE name for Synchros made ONLY by...**

FORD

Telesyn **Generators and Motors for transmitting angular positions.**

Telesyn **Control Transformers for voltage indication and servo control.**

Telesyn **Differential Generators and Motors for addition and subtraction.**

FORD

FIND OUT ABOUT FORD TELESYNS—WRITE FOR CATALOG

FORD INSTRUMENT CO.
Division of The Sperry Corporation
31-10 Thomson Avenue, Long Island City 1, N. Y.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 103A)

A Survey of Advertising Preferences of Members of The Institute of Radio Engineers

In December, 1950, the Advertising Department of the Institute initiated a survey to determine what advertisements were most acceptable and helpful to the membership—and why.

To obtain the information a Post Card (see illustration) was mailed to a portion of the membership representing a good cross-section of the country. This will be done each month, until the entire roster has been polled.

The reason why a member liked an advertisement fell into the following "pattern" (not necessarily in order of preference).

1. Specifications or Data.
2. Prices Quoted.
3. Application Data.
4. Engineering Drawing, Charts, Graphs, or Wiring Plan.
5. Good Visual Display—Attracts Attention.
6. Brief Yet Complete.
7. Dignified Presentation.
8. Generally Informative or Instructive.
9. Performance Characteristics.

(Continued on page 107A)

no other tape recorder like...!

AMPEX
STANDARD OF THE GREAT RADIO SHOWS

to 40,000 cps at 30 inches per second tape speed

•

to 15,000 cps half-track at 7½ inches per second tape speed

AMPEX ELECTRIC CORPORATION
San Carlos, California

SOLD BY...
BING CROSBY ENTERPRISES, INC., Hollywood
AUDIO-VIDEO PRODUCTS CORP., New York City
GRAYBAR ELECTRIC CO., All Principal Cities
TERMINAL RADIO CORP., New York City
RADIO SHACK CORPORATION, Boston
NEWARK ELECTRIC CO., Chicago
WESTREX CORP. (Export), New York City

AX-34

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 106A)

10. No Ballyhoo or Advertising Blurbs.
11. No Answer.
12. Definitely Negative.

Other Reasons Infrequently Given—
- A. New Techniques.
- B. Order Blank in Ad.
- C. Physical Dimensions.
- D. New Product.
- E. Cut Away Drawing or Exploded View.
- F. Invites Correspondence.

The recipient of the card is requested to make a choice for the specific month, and then to state the reason for selection. Next, to choose an advertisement from the IRE Directory. Thirdly to state his type of business; and last to tell us if (A) he makes purchases, (B) sets specifications, (C) can influence buying, (D) has no interest in buying. Each of the last group is given a numerical value which is totaled to obtain a "point evaluation" of the men who prefer the ad.

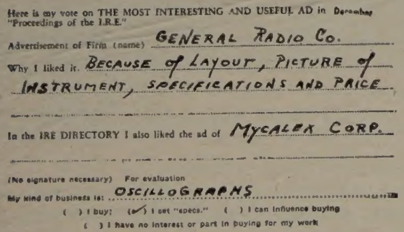
This is the result of the February study. (3rd report)

Firm & Page	Vote	Ans.	Value
Hewlett-Packard Co. Page 7A	31	1	84
General Radio Co. Cover IV	12	1	32
General Ceramics & Steatite Corp. Page 49A	12	1	32
Centralab, Div. Globe-Union Inc. Pgs. 33, 34, 35A	10	8	28
Helipot Corp. Page 15A	6	1	21
A. B. DuMont Labs., Inc. Page 12A	6	8	15
Ballatine Labs., Inc. Page 38A	6	1	14
Radio Corp. of America Page 32A	5	1 & 5	10
Electrical Reactance Corp. Page 17A	6	1 & 6	13
Bell Telephone Labs., Inc. Page 4A	5	5 & 8	9

Only the top group of votes are reported.

Firm & Page	Vote	Ans.
Mycalex Corps. of America Insert	11	Directory
General Radio Co. Pages 234 & 235	6	Directory
Communication Prods. Co. Inc. Insert	4	Directory
Hewlett-Packard Co. Pages 232 & 233	4	Directory

NOTE: *Vote* indicates total votes.
Ans. indicates the answer most frequently given, or in a tie, both.
Value indicates point evaluation total of voters.
Directory refers to the IRE Directory.



Here is my vote on THE MOST INTERESTING AND USEFUL AD in December "Proceedings of the I.R.E."

Advertisement of Firm (name) GENERAL RADIO CO.

Why I liked it. BECAUSE OF LAYOUT, PICTURE OF INSTRUMENT, SPECIFICATIONS AND PRICE

In the IRE DIRECTORY I also liked the ad of MYCALEX CORP.

(No signature necessary) For evaluation

My kind of business is: OSCILLOGRAPHS

( ) I buy; (✓) I set "specs." ( ) I can influence buying

( ) I have no interest or part in buying for my work

More than one reason was given by most men as the basis for selecting an ad. To avoid making a prejudiced selection the researcher took the first reason in 90 per cent of the answers, on the basis that the most important factor would be stated first. This may be a fallacy, however, interpretation was avoided, in an attempt to be factual.

(Continued on page 108A)

Airtron DESIGNS AND PRODUCES

Flexible and Rigid WAVEGUIDE COMPONENTS

Airtron
JAN 1863A
PART NO

Special Microwave Mixer-Duplexer Assembly Designed by AIRTRON

From the smallest waveguide component to complete transmission systems... from the first "doodle" memo or blueprint to the finished precision product . . . make AIRTRON your FIRST source for all types of microwave plumbing. Unique in background, technical savvy, plant facilities and the WILL to SERVE, this organization is prepared to engineer and manufacture your staple or special requirements in:

Mixers
Duplexer Assemblies
Magic Tees
Waveguide Switches
Elbow Bends
Elbow Miters
Twisted Sections
Rigid Twists
Choke Fittings
Flexible Waveguides
Straight Section
Rotary Joints

Send for AIRTRON Engineering Data on Microwave Plumbing

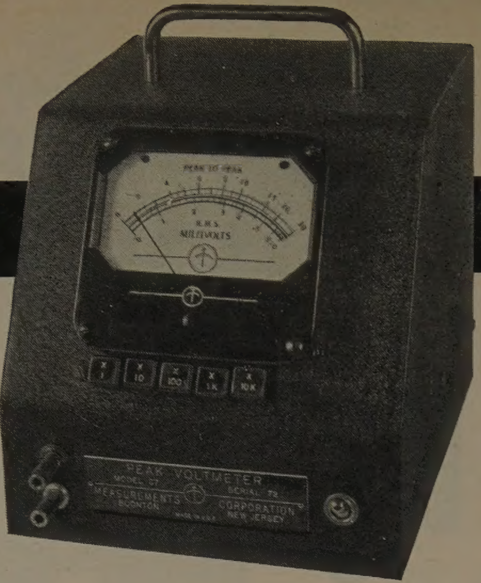
Airtron INC.
105 East Elizabeth Ave., Linden, New Jersey
BRANCH OFFICES
Baltimore Los Angeles New York
Boston St. Louis Dallas Dayton

MEASUREMENTS CORPORATION

Peak-to-Peak VOLTMETER

.0005—300 VOLTS

MODEL 67



Designed for accurate indication of the peak-to-peak values of symmetrical and asymmetrical waveforms, varying from low frequency square waves to pulses of less than five microseconds duration.

.0005-300 volts peak-to-peak, .0002-100 volts r. m. s. in five ranges. Semi-logarithmic, hand calibrated scales.

Provision for connection to 1500 ohm, 1 milliampere graphic recorder or milliammeter.

INPUT IMPEDANCE: 1 megohm shunted by 30 mmfd.
DIMENSIONS: Height 7½″, width 7″, depth 8½″. Weight 8 lbs.
POWER SUPPLY: 117 volts, 50-60 cycles, 35 watts.

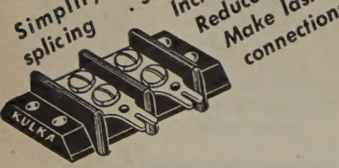
MEASUREMENTS CORPORATION
BOONTON NEW JERSEY

KULKA TERMINAL BLOCKS

KULKA
KULKA

FOR ELECTRONIC EQUIPMENT AND LIGHTING FIXTURES

Simplify your wiring work . . . Eliminate splicing . Stop leaks and shorts . . . Increase insulation . . . Reduce assembly costs. Make lasting connections.



Blocks come in 4 sizes — with 1-23 terminals. Brass screws and solder lugs. Lugs in several styles for all sizes — also eyeletted to block. Marker strips imprinted or plain, or blocks engraved.

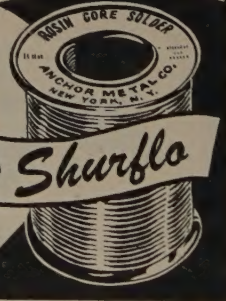
GET THIS CATALOG

KULKA ELECTRIC MFG. CO. Inc.
30 South St., Mount Vernon, N.Y.

OFFICIALLY APPROVED
by the Nation's Foremost ELECTRONIC MANUFACTURERS!

ANCHOR

★ Exceeds ASTM Specifications
★ Conforms with JAN(AN-S-62) Specifications



Activated Rosin-Core Solder

The *SHURFLO* Rosin: Speeds up solder flow 25%. Spreads as much as 30% further than ordinary rosin. Has superior wetting and oxide-removing action. Is non-corrosive, non-conductive, safe. Gives no unpleasant odor. Does not carbonize.

Specially designed for *all* electronic needs. Makes perfect joints on common and difficult metals. 30% more economical to use. Supplied in 1, 5, 20 lb. spools—gauges as *fine as 0.020″*.

Send NOW for generous Free Sample and Catalog P-5.

ANCHOR METAL COMPANY
87 Walker St., N. Y. 13, N. Y.
Phone WAlker 5-2569

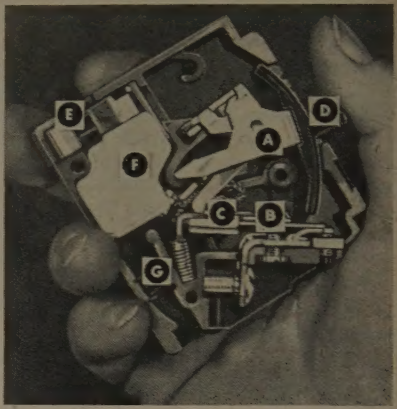
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 107A)

Plugin Circuit Breaker

A new plugin-type circuit breaker for 15-to-50 ampere services, featuring quick-make, quick-break operation and thermal-magnetic projection, has been introduced by **The Trumbull Electric Manufacturing Co.,** Plainville, Conn., for application in a new line of load centers and panelboards.



The breaker is tripped by either of two impulses. Thermal action of the bimetal trip element responds to an overload condition, although harmless temporary overloads will be passed without opening the circuit and magnetic action instantly opens the breaker in case of a short circuit.

The breaker mechanism trips independently of the handle and cannot be held in the ON position in case of an overload or short.

The TQL Breaker also incorporates an arc, and an extended exhaust chamber for cooling the gases before venting.

Grid-Controlled Rectifier

A new Xenon gas-filled grid-controlled rectifier tube type EL CIK has been announced by **Electrons, Inc.,** 127 Sussex Ave., Newark 4, N. J.

ELECTRONS INC. NEWARK
CIK

The EL CIK, a temperature-free thyratron, may be used in applications such as motor control, high-speed or synchronous switching, servo amplifiers, temperature controls, and regulated dc power supplies.

Electrical ratings and characteristics are: average anode current 1 ampere dc; peak anode current 8 amperes; maximum peak inverse voltage 1,250; maximum peak forward voltage 1,000. The average arc drop is 8 volts and the filament draws 6.3 amperes at 2.5 volts with a heating time of 25 seconds. Grid shielding results in a grid-anode capacitance of only 1 $\mu\mu f$ with a grid-cathode capacitance of 10 $\mu\mu f$. Critical grid current is less than 5 microamperes. Seated height $3\frac{1}{2}$ inches.